INFOMAR Survey Report: CE20_01
Area: Celtic Sea

Marine Institute & Geological Survey Ireland

RV *Celtic Explorer*

March & April 2020

Prepared by Kevin Sheehan & INFOMAR Survey Team

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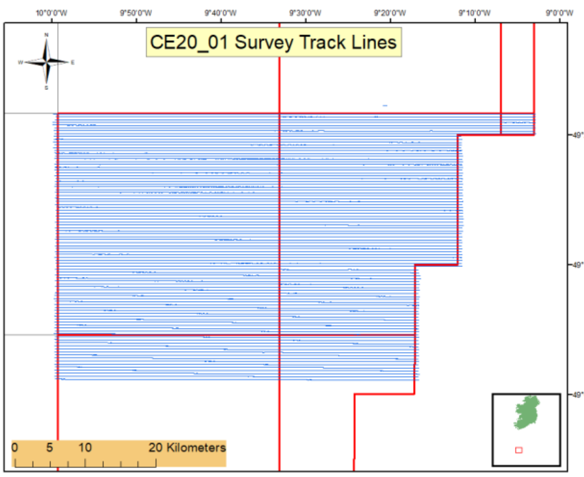
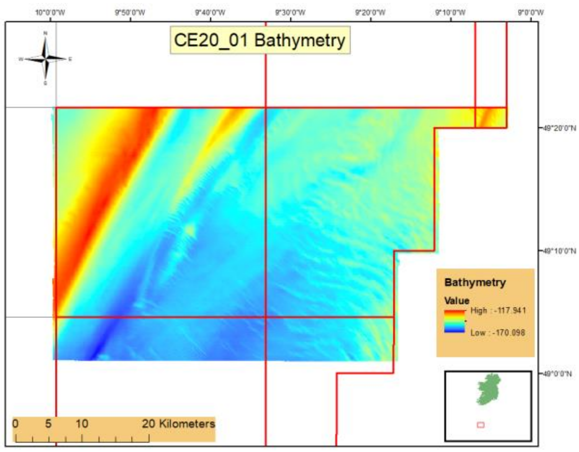
Issue	Change	Date	Description	By	Approved
1		16/12/2020	Draft	K. Sheehan	O. McManus
2		11/01/2021	Final	K. Sheehan	

Executive Summary			
Survey Summary			
Survey Vessel:	R.V. Celtic Explorer	**Survey Leg:**	CE20_01
Mobilisation:	Galway	**Demobilisation:**	Galway
Survey Areas:	Celtic Sea	**Start Date:** **End Date:**	25/03/2020 11/04/2020
Northeast Boundary	49º 21.735N 09º 2.848W	**Southwest Boundary**	49º 00.813N 09º 59.166W
UKHO Admiralty	0002 (1:1,500,000)		
Key References	CE20_01 Survey Leg Report		
Equipment Used	EM2040 & EM302 multibeams, iXblue Echoes 3500 T7 Chirp, AML MVP200, Valeport SVP Mini, C-Nav 3050 GNSS.		
Survey Statistics			
Minimum Water Depth (VORF LAT):	118 m	**Maximum Water Depth (VORF LAT):**	170 m
Area Covered:	2180 km^2	**Survey Line Kilometres:**	5343 km
Approximate Operational:	82%	**Downtime :**	0%
Groundtruthing Stations:	0	**Wrecks**	6
H525 forms issues (wrecks)	6	**H102 forms issued (shoals)**	0
Survey Track Lines		**Bathymetry**	





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List of Acronyms Used Within This Report

Acronym	**Full Name**
AML	AML Oceanographic
CTD	Conductivity Temperature Depth
CUBE	Combined Uncertainty and Bathymetry Estimator
DECC	Department of the Environment, Climate and Communications
DGNSS	Differential Global Navigation Satellite Systems
DPR	Daily Progress Report
ETRF	European Terrestrial Reference Frame
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GSI	Geological Survey Ireland
HSE	Health Safety & Environment
HVF	Hips Vessel File
IHO	International Hydrographic Organisation
INFOMAR	INtegrated Mapping FOr the Sustainable Development of Irelands MArine Resource
INSS	Irish National Seabed Survey
ITRF2014	The International Terrestrial Reference Frame
LAT	Lowest Astronomical Tide
MBES	Multibeam Echo-Sounder
MVP	Moving Vessel Profiler
MI	Marine Institute
MRU	Motion Reference Unit
NPWS	National Parks & Wildlife Service
PPE	Personal Protective Equipment
PPS	Pulse Per Second
PPP	Precise Point Positioning
PU	Processing Unit
QINSy	Quality Integrated Navigation System
RTG	Real Time Gypsy
RV	Research Vessel
SBP	Sub-Bottom Profiler
SBES	Singlebeam Echo Sounder
SIS	Seafloor Information System

SVP	Sound Velocity Profile
TPU	Total Propagated Uncertainty
UKHO	UK Hydrographic Office
UTC	Coordinated Universal Time
VORF	Vertical Offshore Reference Frame
WGS	World Geodetic System

1 Introduction

1.1 Project Overview and Objectives

The Geological Survey Ireland (GSI) and Marine Institute (MI) conducted seabed mapping between 2003 and 2005 under the auspices of the Irish National Seabed Survey (INSS) and from 2006 to present day under the INtegrated mapping FOr the sustainable development of Irelands MArine Resource (INFOMAR) programme. INFOMAR is a joint venture between the GSI and the MI. The programme succeeded the INSS which was one of the largest marine mapping programmes ever undertaken, with a focus on deep water mapping. INFOMAR is funded by the Irish Government through the Department of the Environment, Climate and Communications (DECC).

INFOMAR Phase 1, 2006 to 2015 focused on mapping 26 priority bays and 3 priority areas around Ireland and creating a range of integrated mapping products of the physical, chemical and biological features of the seabed in those areas. INFOMAR Phase 2, 2016 to 2026 intends to map the remainder of Ireland’s entire seabed. Figure 1 shows the extent of the mapped area under INSS and INFOMAR and the outstanding areas as of January 2020. Grey have already been mapped, blue and coloured hatched areas are unmapped.

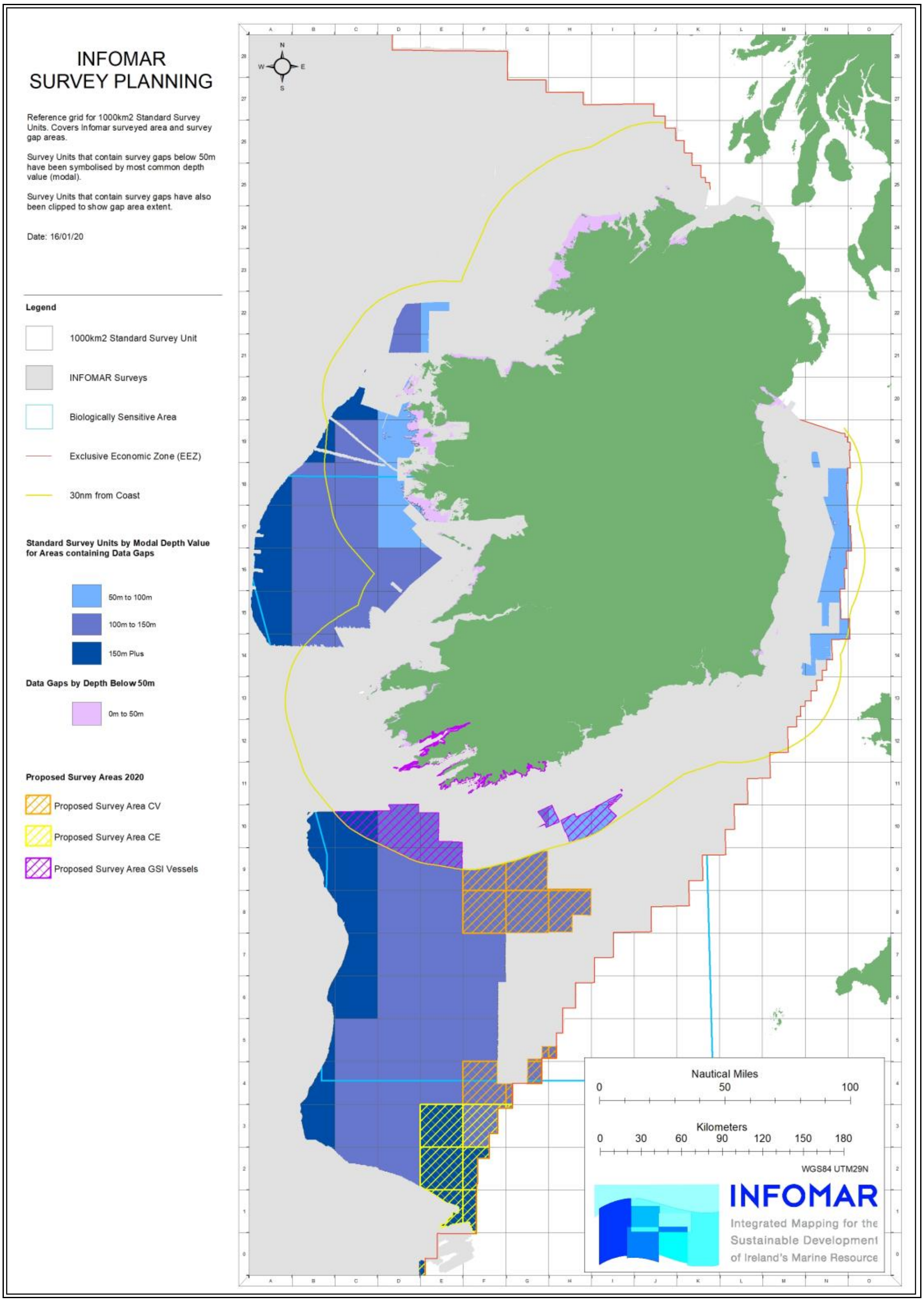


Figure 1: Survey coverage status January 2020.

MI supplied the research vessel RV *Celtic Explorer* and experienced contractors for the survey.

The scientific aims of the survey were to:

(i) Undertake a Multibeam Echo Sounder (MBES) hydrographic survey to a minimum standard of International Hydrographic Organisation (IHO) Order 2.

(ii) Produce bathymetry, shaded relief and backscatter mosaic products to provide depth, seabed features and seabed hardness/roughness information.

(iii) Acquire Sub Bottom Profiler (SBP) data of the shallow (up to 30 metres) sub seabed to determine the existence of buried objects and ascertain the sub-seabed character.

(iv) To map in detail and provide hydrographic wreck reports on any wrecks.

(v) To acquire water column data from the EM2040 and EM302 MBES.

(vi) To acquire Moving Vessel Profiler (MVP) data for calibration of the acoustic data and investigation of the thermocline.

1.2 Survey Area

Figure 2 shows the designated survey area in yellow hatching. The RV *Celtic Explorer* designated area is located near the southern end of our unmapped area. The inset image shows the overall shelf coverage to date. Mapped areas are in grey and unmapped in white. The entire area is split into 1000 km^2 grids, orientated north-south and east-west. The RV *Celtic Explorer* and RV *Celtic Voyager survey* areas are located in the Celtic Sea in sites selected for their strategic fisheries importance and for optimum deployment of our vessel resources. Acquisition commenced at the northern edge of the proposed area in Figure 2.

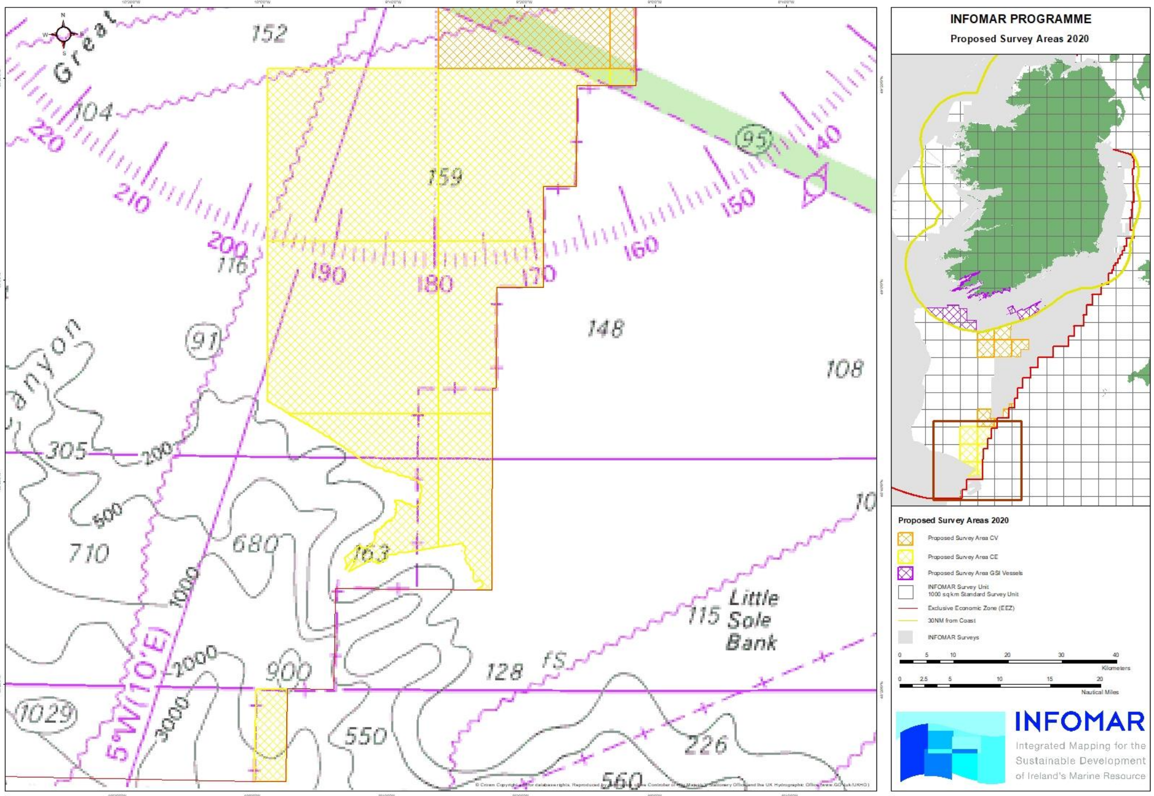


Figure 2: RV *Celtic Explorer* proposed survey areas for 2020.

2 Operations

Mobilisation took place in Galway City on 25th March. Data acquisition took place between 26th March and 9th April with Agust Magnusson as Party Chief and Ger Sullivan as surveyor. A skeleton survey team was aboard due to the Covid 19 emergency.

2.1 Survey Track Lines

The final survey track line plot is shown in Figure 3. Main lines were run along east – west reciprocal headings with cross lines on north - south reciprocal headings.

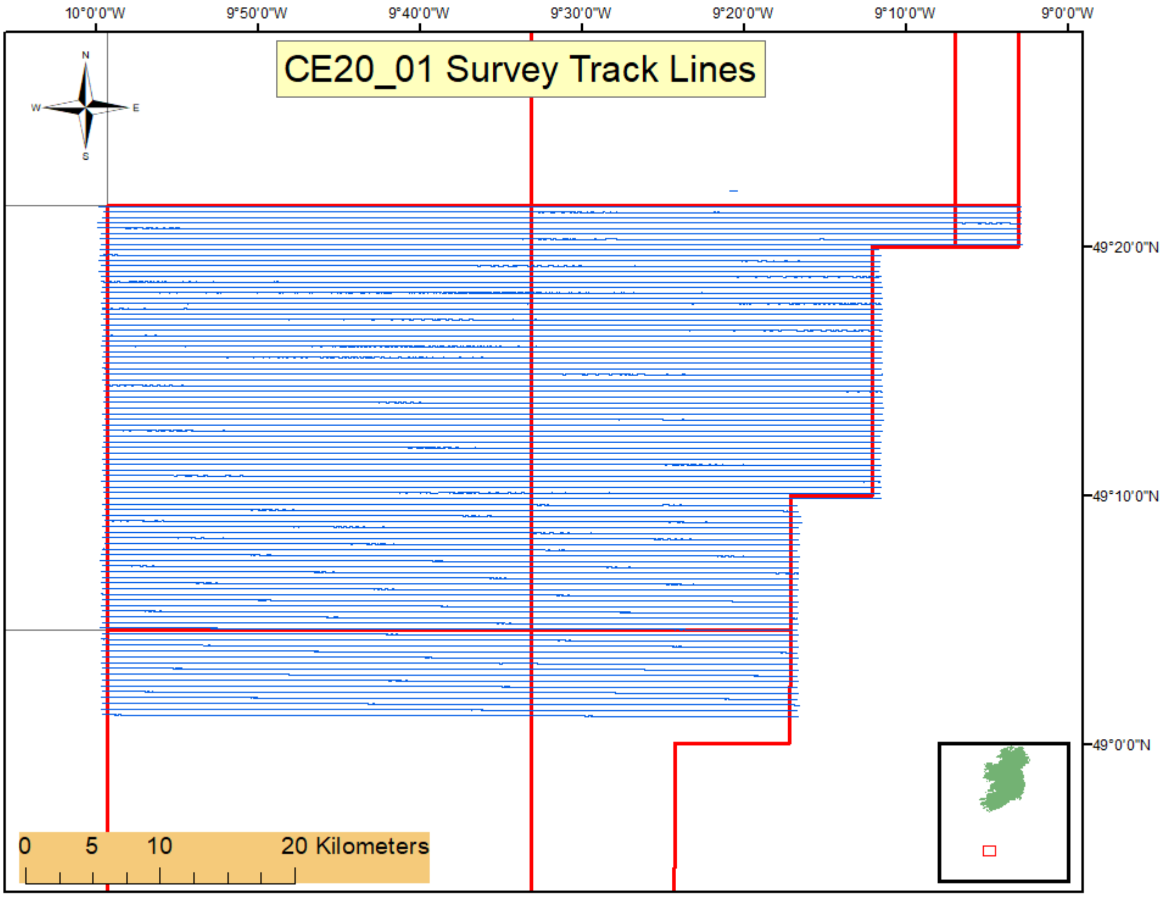


Figure 3: Survey track line plot produced in ArcGIS software.

2.2 Summary of Events

A summary of the key events is presented in Table 1. Times are in Coordinated Universal Time (UTC). Daily Progress Reports (DPRs) were emailed to management and INFOMAR personnel on a daily basis.

Date and time	Activity	Comments
25/03/20 05:30	Depart Galway Port	
25/03/20 08:30	EM2040 Calibration	Near Aran Islands
25/03/20 12:24	Transit to Celtic Sea	
26/03/20 09:30	Commence Operations	
28/03/20 21:15	MVP Recovery	35 knot wind speed
29/03/20 19:00	MVP Redeployment	
05/04/20 15:00	MVP Repairs	Water Ingress
09/04/20 22:00	Commence Cross Lines	
10/04/20 05:00	Finish Cross Lines	Transit to Galway
11/04/20 07:00	Arrive Galway	
11/04/20 23:59	Demobilisation completed	

Table 1: Summary of survey events.

2.3 Survey Personnel

Survey personnel are listed in Table 2.

Name	Affiliation	Role
Agust Magnusson	Freelance	Party Chief / Surveyor
Ger Sullivan	Freelance	Surveyor

Table 2: Survey personnel details.

2.4 Health, Safety and Environment (HSE)

All personnel joining the vessel were given a safety induction tour which was recorded by the Second Mate. Medical and Personal Sea Survival certifications for all personnel were checked for validity prior to departure. A muster drill was held within 24 hours of departure from port. Magnetometer, grab and sound velocity profiler deployments were performed by vessel crew and without incident, with personnel wearing correct Personal Protective Equipment (PPE). There were no near misses or safety incidents to report.

2.5 Marine Mammal Observations

National Parks and Wildlife Service (NPWS) published a *Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters* in 2007. An updated document titled "Guidance to Manage the Risk to Marine Mammals from Man-made Sound Sources in Irish Waters" was published in January 2014. Full details of both documents are published on the NPWS website. The code and guidance are applicable to all seismic, MBES and sidescan sonar surveys in bays, inlets or estuaries and within 1500 m of the entrance of enclosed bays/inlets/estuaries. All CE20_01 operations were outside of the areas covered under the above guidelines.

2.6 General Survey Information

A summary of principal survey statistics is contained in Figure 4. The vessel was operational 82% of the time and had no weather standby. Survey operations were at reduced speed at times due to strong winds and rough seas but this is not accounted for in the statistics. A total of 5343 line km and 2180 km^2 were covered.

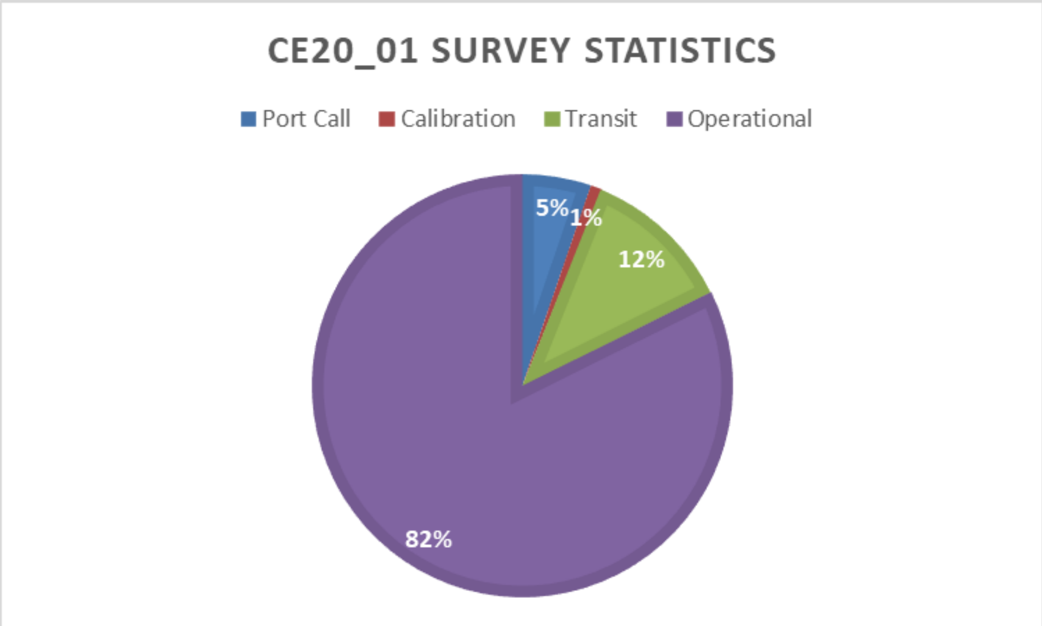


Figure 4: Survey statistics pie chart CE20_01.

2.7 Wreck and Shoal Investigations

United Kingdom Hydrographic Office (UKHO) guidelines are usually implemented for wreck investigations. Investigations usually have three survey lines along the wreck's primary axis with high overlap and one line across its secondary axis (ensuring full wreck coverage along both axes). Beam angles, survey speed, operational frequency and pulse length are configured for maximum resolution. Crewing restrictions due to Covid 19 meant the absence of an onboard data processor resulting in wrecks not being identified during the survey and so no detailed wreck investigations were completed.

Post-cruise data processing identified seven wrecks and UKHO wrecks forms were completed for each of these. Wreck reports were produced and distributed to the Underwater Archaeology Unit and UKHO. Table 3 contains wreck metadata information. No shoals were identified.

Descriptor	Metadata
Shoals	0
Wrecks	7

Table 3: Hydrographic reports completed.

3 Survey Vessel Offsets, Equipment and Data Acquisition

The RV *Celtic Explorer* (Figure 5) is a multipurpose research vessel owned by MI and managed by P&O Maritime. The vessel has wet, dry and chemical laboratories, which are permanently fitted with standard scientific equipment and can accommodate 35 people with a maximum endurance of 45 days. It has three high resolution MBES systems, a Singlebeam Echo Sounder (SBES), fisheries echo sounder, chirp source SBP and C-NAV Differential Global Navigation Satellite Systems (DGNSS). All necessary geophysical and DGPS positioning equipment were pre-installed, calibrated and tested prior to commencement of survey activities.

Figure 5: The RV *Celtic Explorer*.

Detailed vessel information is contained in Table 4.

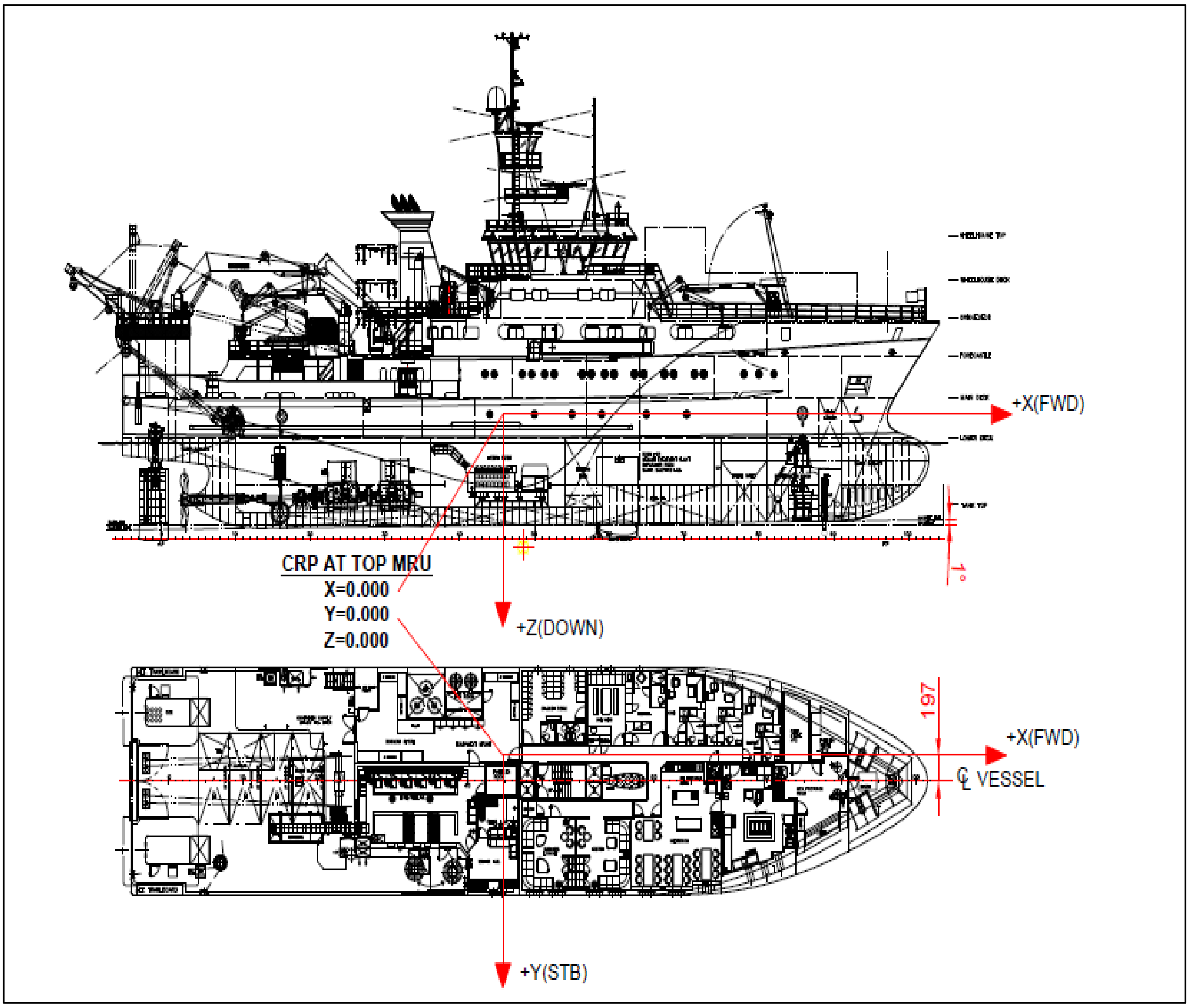
Length	65.5 m
Beam	15 m
Draught	6.0 m
Engine	1 x 6L20, 2 x 9L20
Power Output	1 x 1080 kWa, 2 x 1680 kWa
Speed	10 knots
Fuel	4600 Lt per day MGO
Generator	1 x 1080 kWa, 2 x 1680 kWa

Max Scientists and Crew	35
Passenger Licence	P5

Table 4: RV *Celtic Explorer* vessel information.

3.1 Vessel Offsets

Bluepix AS performed a vessel offset survey between 10th and 15th January 2015 while the vessel was in dry dock in Falmouth, UK. An EM302 deep water MBES and an IxBlue ECHOES3500 Chirp system were installed on the vessels hull during this dry dock. Vessel offsets are presented in Table 5 below.



Item	Y (+Stb)	X (+Fwd)	Z (+Down)	Description
MRU5+	0,000	0,000	0,000	Position Centre Top
EM302 TX	0,199	20,022	7,056	Position Centre Face
EM302 RX	0,202	17,574	7,106	Position Centre Face
EM 2040 TX	0,416	11,204	7,205	Position Centre Face
EM 2040 RX	0,111	11,098	7,192	Position Centre Face
EM 1002	0,195	13,846	7,964	Position Centre U/S
Seapath aft	0,235	1,506	-25,006	Geometric Centre
Seapath Fore	0,205	3,980	-24,966	Geometric Centre
C-Nav	-0,211	2,838	-24,925	Geometric Centre U/S Antenna
IXSEA ECHOS SBP	0,194	16,317	7,130	Centre Face
ES 120	-0,073	12,289	7,161	Centre Face
ES 38	0,199	12,581	7,160	Centre Face
ES 200	0,474	12,290	7,167	Centre Face
ES 18	0,203	11,901	7,171	Centre Face
USBL 1 and 2	0,212	9,988	7,239	Flush U/S Drop keel
Draftsensor Fore Stb	3,484	23,316	4,181	Centre Flush Hull
Draftsensor Fore Port	-3,067	23,314	4,185	Centre Flush Hull
Draftsensor Port Midship	-7,053	-5,133	4,436	Centre Flush Hull
Draftsensor Stb Midship	7,608	-4,067	4,400	Centre Flush Hull
Draftsensor Aft Stb	2,064	-14,217	6,240	Centre Flush Hull
Stb Point for draft measurement	7,719	-4,582	-2,179	Railing Stb side
Stb Point for draft measurement	7,147	11,245	-4,985	Welded mark
Port Point for draft measurement	-7,474	-1,969	-4,945	Railing Port side

Item	Pitch	Roll	Yaw
MRU 5+	0.73	-1.11	-0.36
EM2040 TX	1.25	-0.38	-0.23
EM2040 RX	0.55	0.16	-0.12
EM302 TX	1.03	0.42	-0.05
EM302 RX	1.68	0.06	0.04
Seapath	N/A	N/A	-0.70
EM1002	0.86	0.01	-0.65

Positive Yaw is clockwise. Positive Roll is starboard down. Positive Pitch is fore up.

Table 5: Vessel offsets and installation angles.

3.2 Survey Equipment

Table 6 contains information on the survey equipment both permanently installed and available for mobilisation onboard the RV *Celtic Explorer*.

Data System	Make/Model	Comment
Multibeam Echo-Sounder	Kongsberg EM2040	200, 300 & 400 kHz
Multibeam Echo-Sounder	Kongsberg EM302	26.5 to 33.5 kHz
Singlebeam Echo-Sounder	Kongsberg EA600	12, 38 & 200 kHz
Fisheries Echo-Sounder	Kongsberg EK60	18, 38, 120 & 200 kHz

Chirp Sub-Bottom-Profiler	iXblue Echoes 3500 T7	3.5 – 9 kHz
Sidescan Sonar	Edgetech 4200	100 and 500 kHz
Positioning	C-Nav DGNSS	Seapath330+ as secondary
USBL	iXSEA-Gaps	Sonardyne Scout as secondary
Sound Velocity Profilers	Valeport SVX2 & SVP Mini	SV & Conductivity
Moving Velocity Profilers	AML MVP-200	CTD & SVP sensor
Realtime Sound Velocity	Valeport & AML	
Magnetometers	SEASPY	Overhauser Effect
Acoustic Doppler Current Profiler	Teledyne	76.8 kHz

Table 6: RV *Celtic Explorer* available survey equipment.

3.2.1 Technical Issues

MVP

Several issues were reported with the MVP but all issues were resolved during the survey.

1. Water Ingress to power plug. Plug opened, dried out and tested.
2. Loss of communication with towfish. Re-termination of cable close to the fish connection.
3. Towfish not falling to programmed depth. Software and hardware components reboot.

3.3 Data Acquisition

3.3.1 Geodetic Parameters

Table 7 contains the geodetic parameters used for the survey.

Local Datum Geodetic Parameters	
Datum	ITRF2014
Spheroid	World Geodetic System 1984 (WGS-84)
Semi-Major Axis (a)	6378137.000 m
Semi-Minor Axis (b)	6356752.314 m
First Eccentricity Squared (e^2)	0.0066943800
Inverse Flattening (1/f)	298.257223563
Projection Parameters	
Grid Projection	Universal Transverse Mercator
Central Meridian Zone 29 (CM)	009º West
Origin Latitude (False Lat.)	00.0°
Hemisphere	North

False Easting (FE)	500000.0 m
False Northing (FN)	0.0 m
Scale Factor on CM	0.999600
Units	Metres

Table 7: Geodetic parameters.

3.3.2 Survey Datum, GNSS Tides and VORF Model

Table 7, above details the vertical and horizontal datum applied during operations. Global Navigation Satellite Systems (GNSS) tides do not require accounting for vessel draft or vessel squat values, as recorded depths are related directly to the WGS84 Ellipsoid. These values were reduced to Lowest Astronomical Tide (LAT) using GNSS tidal measurements and by then applying the VORF (Vertical Offshore Reference Frame) model (LAT/WGS84 separation) as illustrated in Figure 6 below.

A validation of the LAT vertical datum output from the VORF model was undertaken between 2013 and 2016, using tide gauges and harmonic analysis, at key locations around the Irish coast.

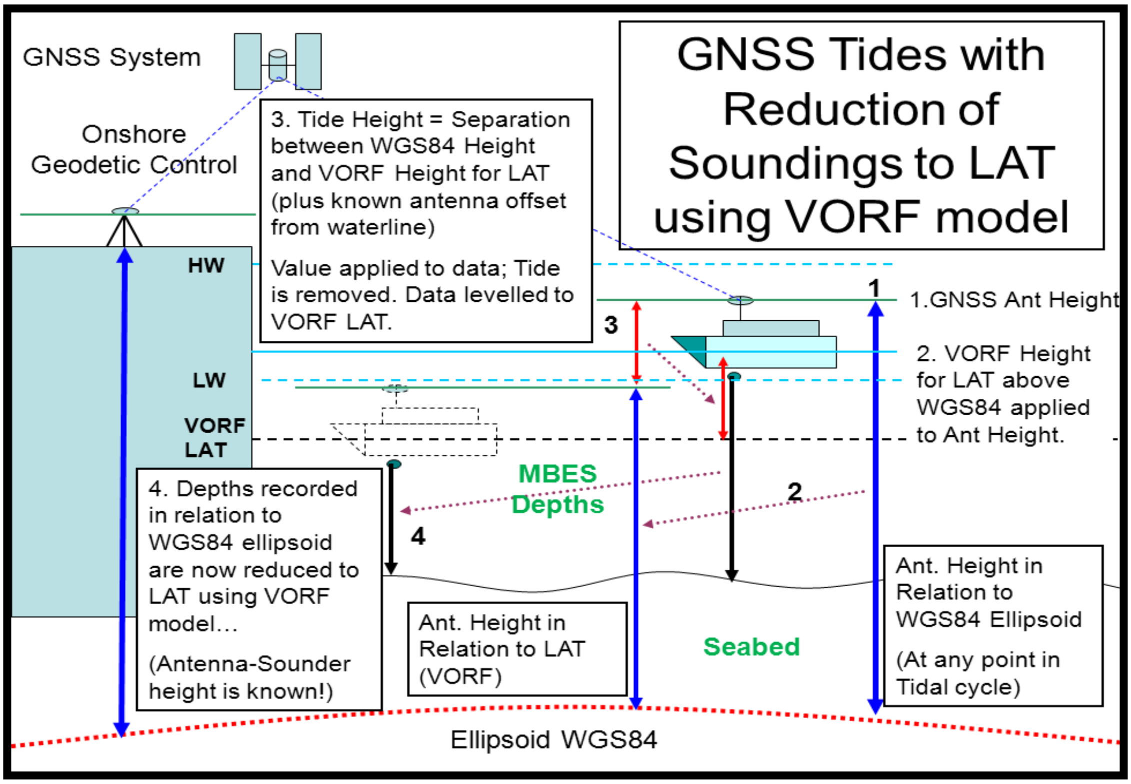


Figure 6: GNSS tides to LAT using VORF model.

3.3.3 Multibeam Systems

The RV *Celtic Explorer* is equipped with two MBES systems; an EM2040 and EM302, capable of high precision seabed mapping from shallow water to full ocean depths. The EM2040 is designed for high resolution mapping down to approximately 400 metres water depth. A hull mounted EM302 provides additional multispectral data and is designed to perform seabed mapping with high resolution and accuracy to a maximum depth of more than 7000 metres.

The EM2040 positioned on the drop keel is the primary system for high resolution seafloor mapping on the continental shelf. First bottom returns from the MBES produce highly accurate bathymetric data. Backscatter acquired by MBES sonars contains important information about the seafloor and its physical properties. This information provides valuable data to aid in seafloor classification and important auxiliary information for a bathymetric survey. The EM2040 can also collect water column data for oceanographic investigations and for detection of objects above the seafloor.

The EM2040 installation consists of single RX transducer and a single TX transducer, 0.7º x 0.7º. The system operates at frequencies of 200, 300 or 400 kHz with 400 soundings per ping and allows coverage of up to 5 times water depth on a flat bottom. It has a maximum ping rate of 50 Hz. The 200 kHz frequency was used for general mapping. Positioning was provided by C-Nav 3050 DGNSS and these data were integrated with inertial measurement units by a Seatex Motion Reference Unit (MRU) model Seapath 330+ to give real time heading, heave, pitch and roll, position and velocity of the MBES system.

The EM302 transducers are modular linear arrays in a Mills cross configuration with separate units for transmit and receive. The transmitter array is 1º resolution and the receive array 2º resolution. It has dual swath capability meaning that 2 swaths are generated per ping cycle, with up to 864 soundings. The system has an operating frequency of 30 kHz. It can also acquire water-column data.

MBES data was recorded in .all and .wcd formats using Kongsberg's SIS software. Raw.all files from the MBESs were continuously backed up on the vessel server. EM2040 water column data was acquired throughout and written straight to portable disk drive as file sizes are very large. Table 8 contains MBES metadata.

Descriptor	Metadata
Survey lines	All
Date Created	25-03-2020 to 10-04-2020
EM2040 Data Files	222
EM302 Data Files	65
EM2040 Dataset Size	53.6 GB
EM2040 Watercolumn Size	Stored on separate disk
EM302 Dataset Size	30.5 GB
EM302 Watercolumn Size	Stored on separate disk
EM2040 File Formats	.all, .wcd
EM302 File Formats	.all, .wcd

Table 8: MBES metadata.

3.3.4 Singlebeam Systems

Singlebeam data were not acquired during this survey.

3.3.5 Echoes Chirp Sub-Bottom Profiler

The vessel is equipped with a hull-mounted SBP situated just behind the EM302. Echoes 3500 T7 is a low frequency chirp SBP, based on seven transducers. The transmitted pulse is frequency and amplitude-modulated. The frequency modulation ranges from 1.7 kHz to 5.5 kHz, centred on 3.5 kHz, with a 100ms Chirp. The selected bandwidth allows for good penetration and high resolution. Acquisition is controlled in Delph acquisition software.

Raw data was recorded in XTF format for each survey line. Positioning data was provided from C-Nav DNSS and MRU data was fed directly from the Seapath 330+. The realtime attitude data can be viewed in the Delph acquisition software but it is not applied to the seismic data in realtime. One set of acquisition parameters, based on 100 m water depth was utilised throughout the survey. Table 9 contains SBP metadata.

Descriptor	Metadata
Survey lines	All
Data Files	412
Date Created	26-03-2020 to 10-04-2020
Dataset Size	145 GB
File Formats	.XTF, .GEO, .PRM & .idx

Table 9: SBP metadata.

3.3.6 Magnetometer

Magnetometer data were not acquired during this survey.

3.3.7 DGPS Systems

C-Nav DGNSS provided the primary navigation. The C-Nav 3050 is a dynamic DGNSS Precise Point Positioning (PPP) system providing accuracy of <0.1 metre horizontally and

0.2 metre vertically. It provides 66 channel tracking, including multi-constellation support for GPS, GLONASS and Galileo. C-Nav provided the primary navigation feed for all survey equipment. C-Nav also provided a reliable GPS tide correction.

The C-Nav DGNSS receiver was connected to the server VDU for QC purposes. C-Nav has a range of QC output displays that were monitored in real-time including number of satellites in use, satellite attitude and angles, vertical accuracy, vessel speed, heading and precise position. GPS signal was always very good and the system never lost the Real Time Gypsy (RTG) solution. Raw C-Nav data were not recorded to disk during this survey but the data is embedded in the MBES and SBP files.

Seapath 330+ provided the secondary navigation. Seapath and C-Nav data were continuously checked in Quality Integrated Navigation System (QINSy) software to ensure data integrity and comparison between the primary and secondary navigation systems remained within tolerance.

3.3.8 Online Navigation

QINSy software was used for navigation acquisition and QC. QINSy performs visual and QA data-feeds from the key acquisition systems. A project template database was created containing all survey configuration parameters relevant to the project. The project template contains the datum, projections, vessel shape, administrative information, as well as vessel offsets and I/O parameters. QINSy uses a sophisticated timing routine based on the Pulse Per Second (PPS) option from the GNSS receiver. All incoming and outgoing data is accurately stamped with a UTC time label.

Survey line and MVP positioning data were recorded in QINSy software in .db and .txt format. QINSy metadata is provided in Table 10.

Descriptor	**Metadata**
Survey lines	All
Data Files	438
Date Created	25-03-2020 to 10-04-2020
Dataset Size	26.1 GB
File Formats	.db & .txt

Table 10: QINSy Navigation metadata.

3.3.9 Sound Velocity Profilers & Sensors

An AML Oceanographic Moving Vessel Profiler (MVP) 200 (Figure 7) was the primary instrument to obtain sound velocity profile data for the echosounders. The major benefit of the MVP is that the vessel did not have to stop to acquire SVP data, resulting in more frequent casts and increased productivity.

Figure 7: AML Oceanographic MVP-200.

The MVP-200 was fitted with a Smart SVP sensor capable of directly acquiring sound velocity data. MVP deployment was controlled from the vessel Dry Lab using Rolls Royce MVP software. The probe was continually towed in the water at 5 metres depth off the starboard aft side and deployed to within 20 metres of the seabed during casts. Sound velocity profiles were extended in SIS and fed directly into both MBES.

Both Valeport and AML sound velocity sensors positioned at the transducer heads provided real time sound velocity input directly to the EM2040 and EM302 respectively. Profile metadata is contained in Table 11.

Descriptor	Metadata
Survey lines	NA
Data Files	1765
Date Created	25-03-2020 to 10-04-2020
Dataset Size	98.4 MB
File Formats	.asvp, .calc, .eng, s10, .s52, .log, .m1, .raw

Table 11: Sound velocity metadata.

3.3.10 Multilog

Multilog was unavailable for metadata logging for the duration.

4 Online QC, Data Processing, Results and Interpretation

The hydrographic survey was performed to International Hydrographic Organization (IHO) survey standards. Table 12 lists the S-44, 6th edition standards for Order 1a and Order 2 surveys. All depths in this survey exceeded 100 metres where underkeel clearance is not an issue. These criteria represent the minimum standard for position, depth accuracy, feature search, feature detection and bathymetric coverage achieved during data acquisition and processing.

	Order 1a (S-44)	Order 2 (S-44)
Description of Areas	Areas where underkeel clearance is considered not to be critical but features of concern to shipping may exist.	Areas generally where a general description of the sea floor is considered adequate.
Max THU allowable (95%C)	Total Horizontal Uncertainty (THU) 5m+5% of depth	Total Horizontal Uncertainty (THU) 20 m+10% of depth
Max TVU allowable (95%C)	Total Vertical Uncertainty (TVU) a = 0.5 metre b = 0.013 $\pm\sqrt{a^2 + (bxd)^2}$	Total Vertical Uncertainty (TVU) a = 1.0 metre b = 0.023 $\pm\sqrt{a^2 + (bxd)^2}$
Feature Search	100%	Recommended but not required
Feature Detection	Cubic Features > 2m (Depths < 40m) 10% depth > 40m	Not specified
Bathymetric Coverage	≤100%	5%

Table 12: IHO S44 v 6th edition standards for hydrographic surveys.

4.1 MBES Online Quality Control

4.1.1 Acquisition Parameters

Most of the important acquisition parameters are set in the Runtime Parameters module of SIS. Figure 8 shows the Sounder Main tab in Runtime Parameters for the EM2040. Max angle and max coverage parameters were adjusted to take account of depth, sea state and seafloor character. Pulse type was set to auto throughout, which based on the angle and coverage settings, defaulted to FM pulse. The 200 kHz frequency was used throughout.

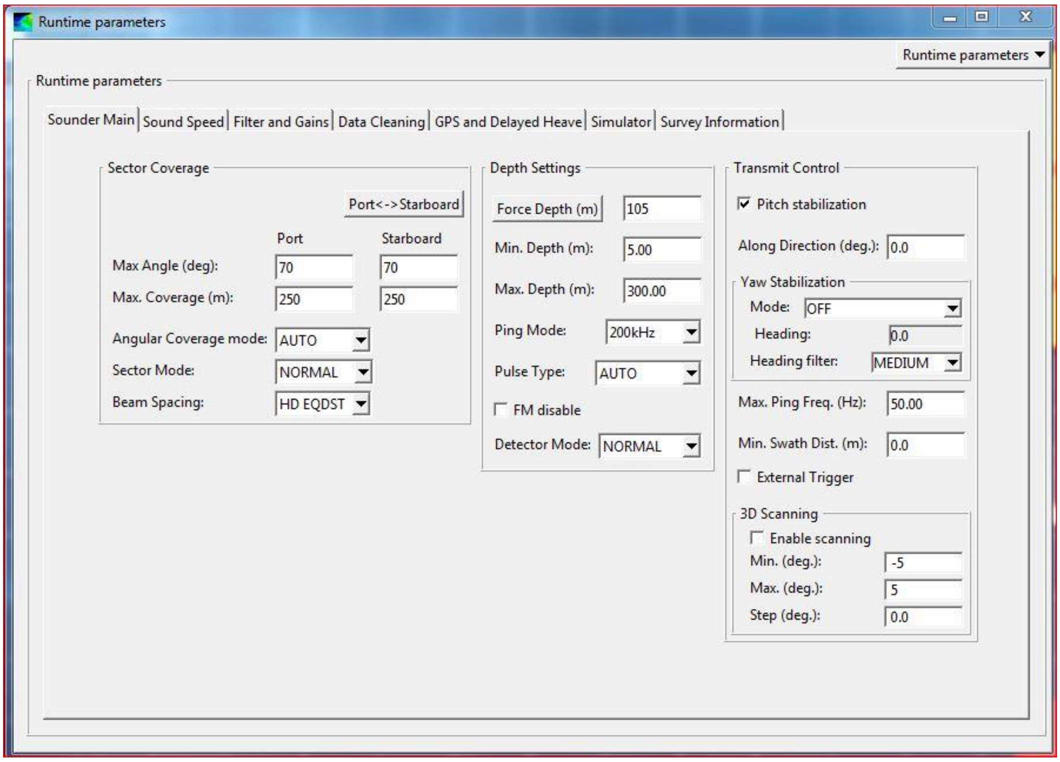


Figure 8: EM2040 runtime parameters window in SIS.

4.1.2 Crossline versus Mainline Statistics

Crossline data were acquired for QC of depth soundings. A total of three crosslines were acquired for statistical analysis in Caris Hips. EM2040 crossline data were compared with mainline data and all crossline data indicated that the soundings exceeded the 95% certainty required for Order 1a specification. Crossline statistics are presented in Table 13.

Line	Beam No.	Count	Max (+)	Min (-)	Mean	Std Dev	Order 1a(%)	Order 2 (%)
0200	1-400	3,420,494	0.916	0.946	0.141	0.146	100	100
0203	1-400	3,004,143	0.866	0.803	0.156	0.168	100	100
0206	1-400	2,679,548	1.417	0.983	0.430	0.200	100	100

Table 13: Multibeam crossline statistics.

4.1.3 Feature Detection, Search and Bathymetric Coverage

The minimum standard for feature detection for an Order 1a survey are cubic features > 2 metres in depths up to 40 metres and cubic features >10% of depth beyond 40 metres. This means that in 40 metres water depth 9 soundings are required in a 2m^2 bin and in 100 metres water depth 9 soundings are required in a 10m^2 bin. Feature detection criteria is not specified in IHO standards for Order 2 surveys.

The bathymetry varies from 118 to 170 metres. Assuming Order 1a, this implies that at the minimum depth value the feature detection criteria is 11.8 metres. A more stringent 10 metre grid was created in order to test the feature criteria. Figure 9 shows the feature detection statistics, i.e. the number of soundings in a 10 metre grid. The mean number of soundings per bin is 38.6, easily exceeding the 9 required for Order 1a feature detection.

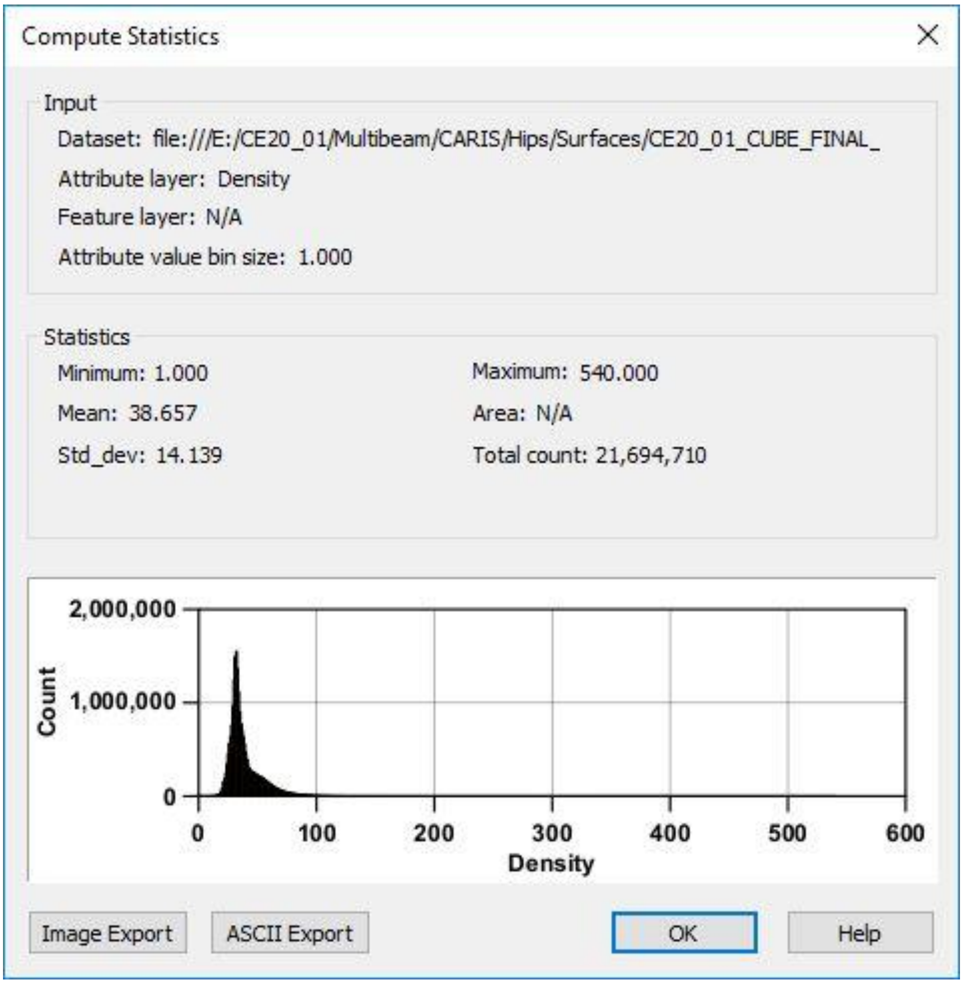


Figure 9: Feature detection statistics.

Figure 10 shows the corresponding sounding density plot for the area with green indicating where at least 9 pings per bin were achieved and red where this failed. Red colours are sporadic on this plot. This plot illustrates that the feature detection criteria for Order 1a was achieved. The data density plot along with the bathymetry image elsewhere in this report demonstrate that 100% bathymetric coverage and feature search of 100% were achieved.

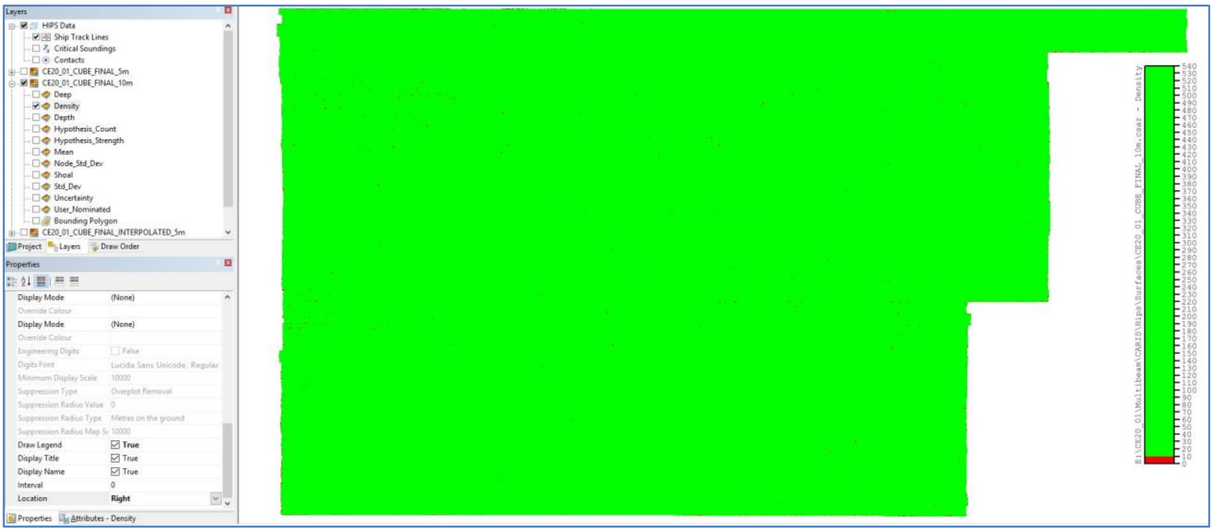


Figure 10: Sounding density QC plot.

4.1.4 Error Budget and Uncertainty Model

Manufacturer values for positioning and sounding errors were factored into the vessel error budget. Vessel offsets were established through an onshore dimension control survey (see section 3.1). In addition; uncertainty levels over positions of soundings were improved through good sound velocity control while surveying. Calibration of the MBES through a standard patch test, combined with good online quality control, ensured that the vessel's error budget fell within IHO 1a specifications.

Table 14 below details Standard Deviation values applied in the calculation of the vessel's Total Propagated Uncertainty (TPU) model. TPU is an estimate of the uncertainty of any individual sounding, taking into account the uncertainty estimates of the component measurements (tide, sound speed, draft, range measurement, angle measurement, attitude, offsets etc). TPU is expressed as a separate value in horizontal and vertical planes. The uncertainty of each sensor was entered in the HIPS Vessel File (HVF) and the TPU calculated.

Heading Accuracy	0.065 deg
Heave	5 cm or 5 % Amplitude
Roll	0.01 deg
Pitch	0.01 deg
Pitch Stabilised	0.00 deg
Position Navigation	0.1 m
Timing Transducer	0.00 s
Timing Navigation	0.00 s
Timing Gyro	0.00 s
Timing Heave / Pitch / Roll	0.00 / 0.00 / 0.00 s

Sound Velocity Measured	0.001 m/s
Sound Velocity Surface	0.001 m/s
Offsets X / Y /Z	X=0.01 / Y=0.01 / Z=0.01
MRU Alignment	Gyro=0.1 / Pitch=0.1 / Roll=0.1
Vessel Speed	0.03
Vessel Loading	0.00
Vessel Draft	0.00 (Use of GPS tides)
Delta Draft	0.00

Table 14: Standard deviation values used in TPU calculation.

4.1.5 Sound Velocity Control

MVP's were acquired frequently. Profiles served the dual purpose of calibrating the echosounders and investigating the characteristics of the water column. Profiles were checked, extended and entered to the online systems as soon as possible. MVP profiles are plotted in Figure 11. Profiles indicate that the water column is well mixed, as one would expect in Spring time in this area.

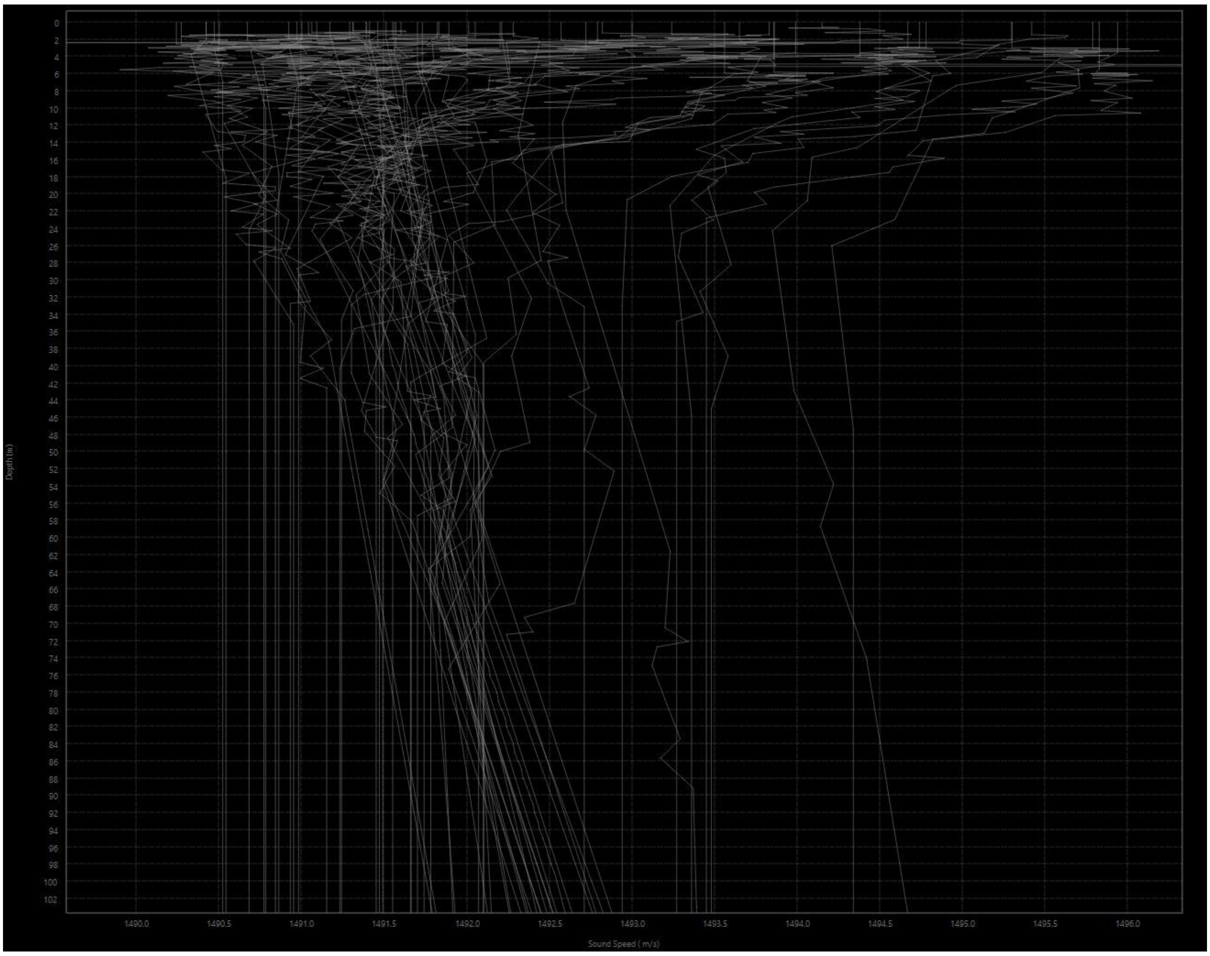


Figure 11: Plotted MVP & SVP casts.

4.2 Post Processing Methods

4.2.1 Navigation

Navigation data was logged in standard C-Nav format. The real time overall quality of the C-Nav positioning system is of high quality and meets IHO Order 1a standard. Vertical errors on the GPS heights are also low (+/- 20 cm) and provide a robust solution for computation of GPS tide.

Navigation data and in particular GPS heights were despiked and smoothed in Caris HIPS. GPS tide was computed using the separation model between European Terrestrial Reference Frame (ETRF) datum and VORF LAT.

4.2.2 Depth Soundings Data Processing

Soundings were edited in Caris HIPS and Qimera processing software against an existing chart background. Combinations of automated and manual processing procedures were applied by experienced data processors to remove systematic errors and obvious outliers. Uncertainty results were examined to ensure they fell within IHO specifications for Order 1a and Order 2 surveys. Processed and cleaned data were subjected to final validation by an experienced and qualified hydrographer. The following is a simplified list of steps undertaken during sounding data processing:

1. Navigation data were applied to survey data.
2. GPS tides were computed using the UKHO's VORF model. This reduced the MBES depth soundings to LAT. GPS tide results were then checked for quality and consistency.
3. TPU values were calculated.
4. SVP data were applied to correct for refraction errors caused by water column heterogeneity. A range of SV algorithms were used to determine the most suitable method of applying SV corrections, for example: nearest in distance versus nearest in time.
5. Qimera's "*TU Delft Sound Speed Inversion*" tool was used to correct refraction issues.
6. Subset Editing was performed in CARIS to clean large "noise" spikes from the data.
7. A CARIS Combined Uncertainty and Bathymetry Estimator (CUBE) base surface was then created to allow CUBE automatic filtering.
8. Final verification of sounding consistency and absence of spikes was carried out using subset editing.

9. Export of final products from Caris: Multibeam Bathymetry grids, Shaded Relief grids, and Backscatter Mosaics. XYZ and track line grids were output.

4.2.3 Backscatter Mosaic Generation

Backscatter is a function of the hardness and roughness of the seafloor. Raw multibeam data was put through the Geocoder engine in Caris HIPS to produce backscatter mosaics of different resolutions.

Raw multibeam backscatter data were also analysed using QPS FMGT, an equivalent backscatter analysis software but with advanced functionalities capable of providing an enhanced backscatter mosaic.

4.3 Survey Results and Data Interpretation

A preliminary interpretation of MBES and SBP data was used to assess bathymetry, seabed texture, seabed features, and shallow geology.

4.3.1 Multibeam Images

EM2040 data were used to produce final data products. Grids and geotiff images were created in Caris Hips software of EM2040 MBES bathymetry and shaded relief data. The backscatter mosaic grid was created in QPS FMGT software. Grids and geotiff images were imported into ArcGIS. Bathymetry and backscatter mosaic tiff images were created in ArcGIS and are presented in Figures 12 to 14 along with a shaded relief tiff image.

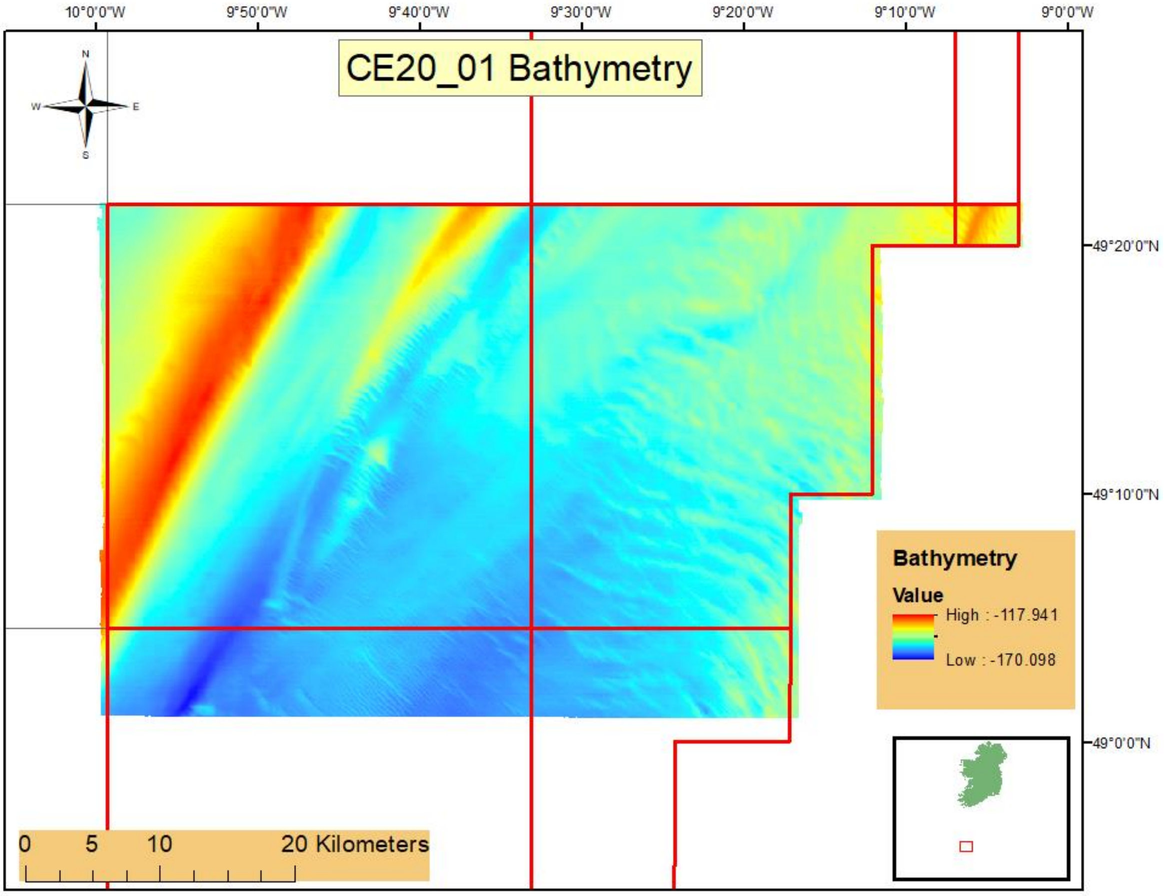


Figure 12: Multibeam bathymetry image.

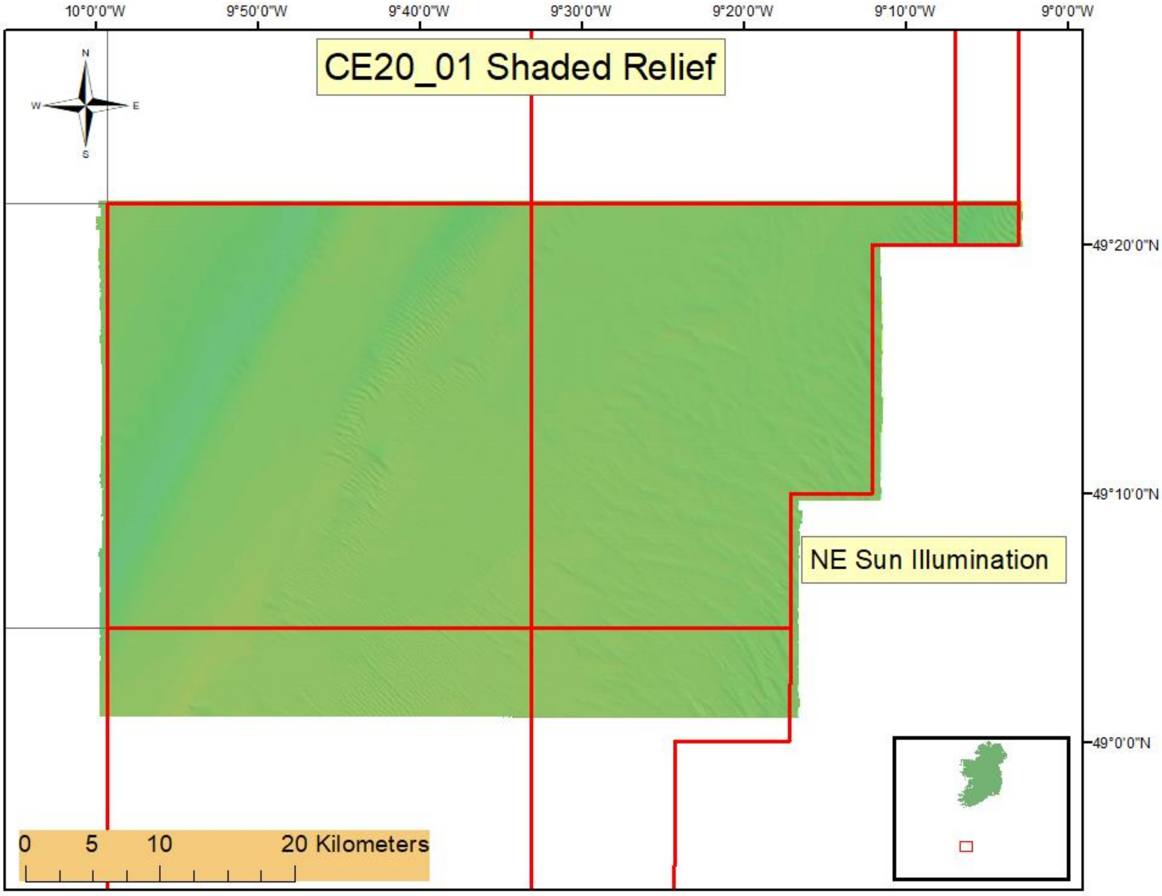


Figure 13: Multibeam shaded relief image.

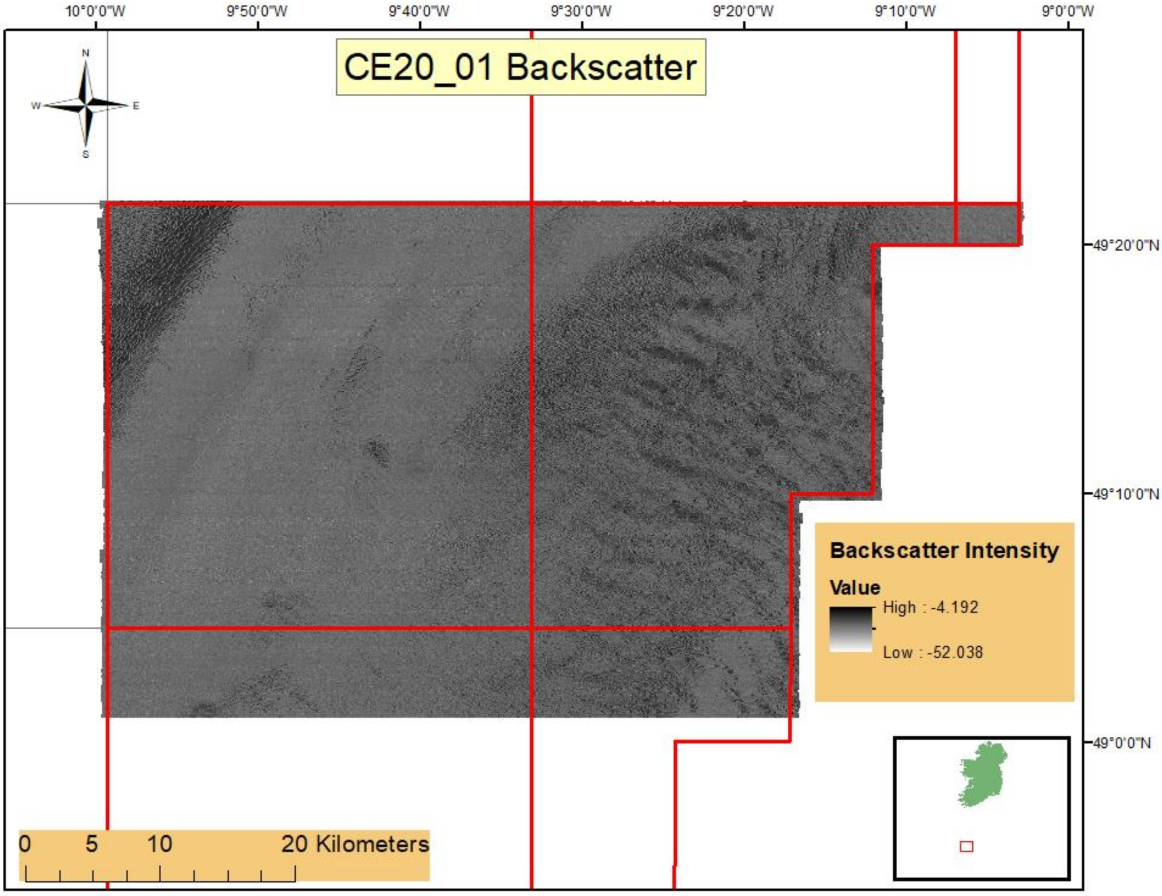


Figure 14: Multibeam backscatter mosaic image.

4.3.2 Shallow Geology Analysis

Data quality and penetration varied depending on prevailing sea state, survey direction and sub-bottom hardness. Survey speed (4-10 knots) was dictated by MBES data quality and weather conditions. Good quality MBES data can be acquired at speeds that compromise SBP data integrity. SBP data was generally of good quality although a very hard substrate in places prevented signal penetration. Profiles illustrated in this report have TVG, AGC, heave correction and stacking applied.

Figure 15 shows the track lines for three profiles, 200, 203 and 99 selected for analysis in this report. Profiles 200 and 203 are cross lines, orientated N-S and profile 99 a main line, orientated E-W. The track lines are overlain on multibeam bathymetry.

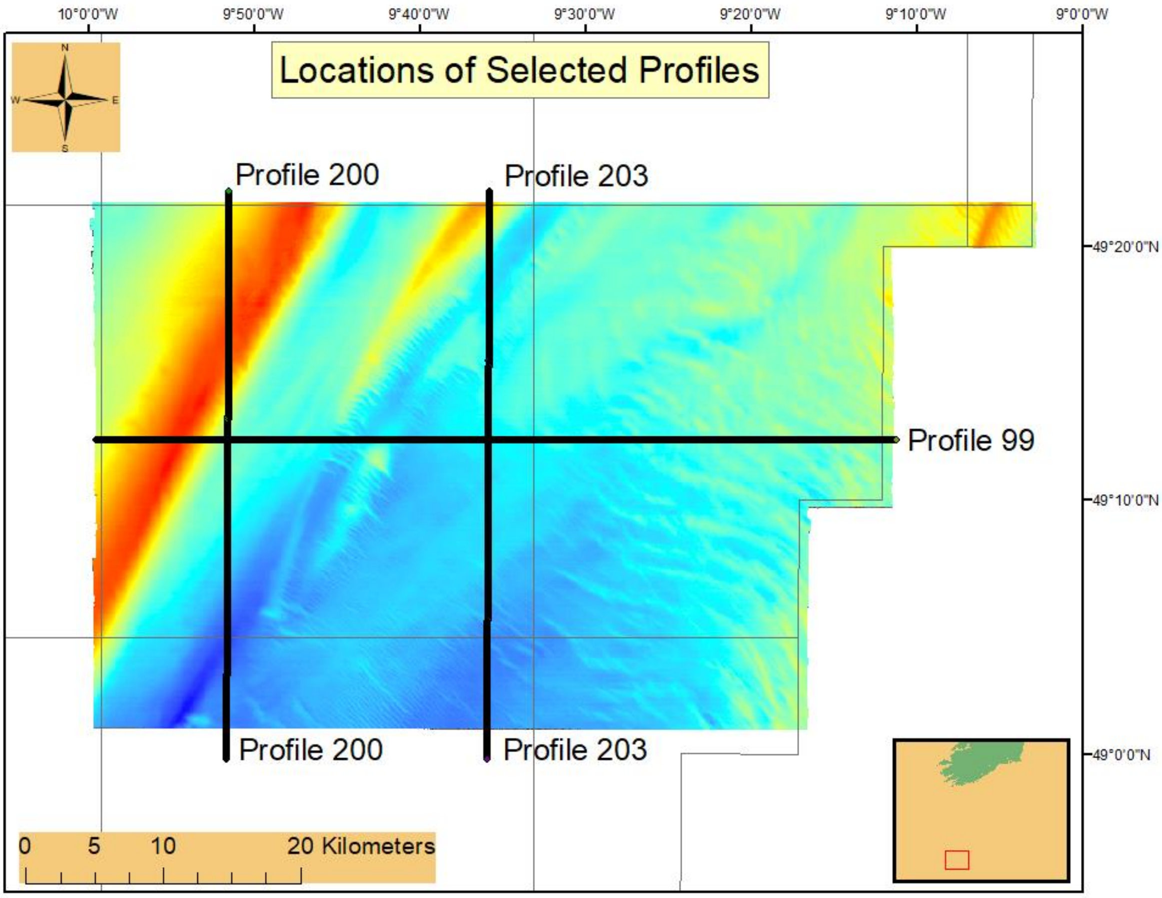


Figure 15: Multibeam bathymetry overlain with tracks of selected profiles.

Profile 200

Figure 16 is an image of SBP line 200. The profile was acquired on a northerly heading. Vertical scale lines are at 25 metre intervals and horizontal scale lines at 1 km. Total profile length is 41.6 km. The seabed topography is dominated by a large ridge, over 30 m in amplitude at the northern part of the profile. Profile and ridge orientations are within approximately 40° so that the ridge has a broad appearance on the profile. It is approximately 18 km in width.

Signal penetration is relatively good as the seabed and near surface sediments are relatively soft over most of the section. Three distinct sedimentary units are identified on the profile. Horizon 2, evident in the southern part of the profile marks the boundary between Unit 3 beneath and Unit 2 above. Horizon 2 is at a depth of approximately 35 metres and can be traced laterally for C. 6 km.

Unit 3 is acoustically featureless. Its base and lateral extent cannot be resolved. Horizon 2, denoting the top of Unit 3 is a sub-horizontal horizon. Unit 2 is above Horizon 2. Unit 2 is 30 metres thick where its top and base can be identified. It appears to comprise dipping internal reflectors.

Horizon 1 marks the top of Unit 2. This is a very strong sub-horizontal reflector which can be seen over most of the section apart from the ridge area. Horizon 2 is reworked at the southern end of the section. Unit 1, above Horizon 1 is up to 15 metres thick. It is acoustically transparent. The sub-bottom beneath the ridge is difficult to discern due to a lack of penetration and/or impedance contrasts. The seabed over the ridge is soft in general which short wavelength crenulations that can only be seen when zoomed in.

Profile 203

Profile line 203 in Figure 17 is located 19 km east of profile 200 and is also orientated north-south. The profile is 41.3 km in length. Horizon 2 is not observed on this profile. Two sedimentary units are identified. Unit 2 is the oldest unit. Its base is not seen. Unit 2 is present over the profile extent. The top of Unit 2 is denoted by the unconformity, Horizon 1. Horizon 1 is an undulating surface with several incised channels. Unit 1 unconformably overlies Unit 2. Unit 1 varies in thickness up to a maximum of approximately 12 metres. Unit 1 contains numerous laterally discontinuous internal reflectors. Sediment waves are evident on the seabed in multiple locations. The sediment waves have amplitudes of less than 3 metres.

Profile 099

Profile line 099 in Figure 18 is located in the centre of the area and is orientated east-west. The profile is 58.1 km in length. Unit 2 is again the oldest unit. Its thickness is unknown. Units 2 is unconformably overlain by unit 1. The unconformity surface is named Horizon 1. Horizon 1 is undulating and channelled. Horizon 1 cannot be traced beneath the ridge. Unit 1 comprises recent sediments with sediment waves of various sizes and symmetries observed.

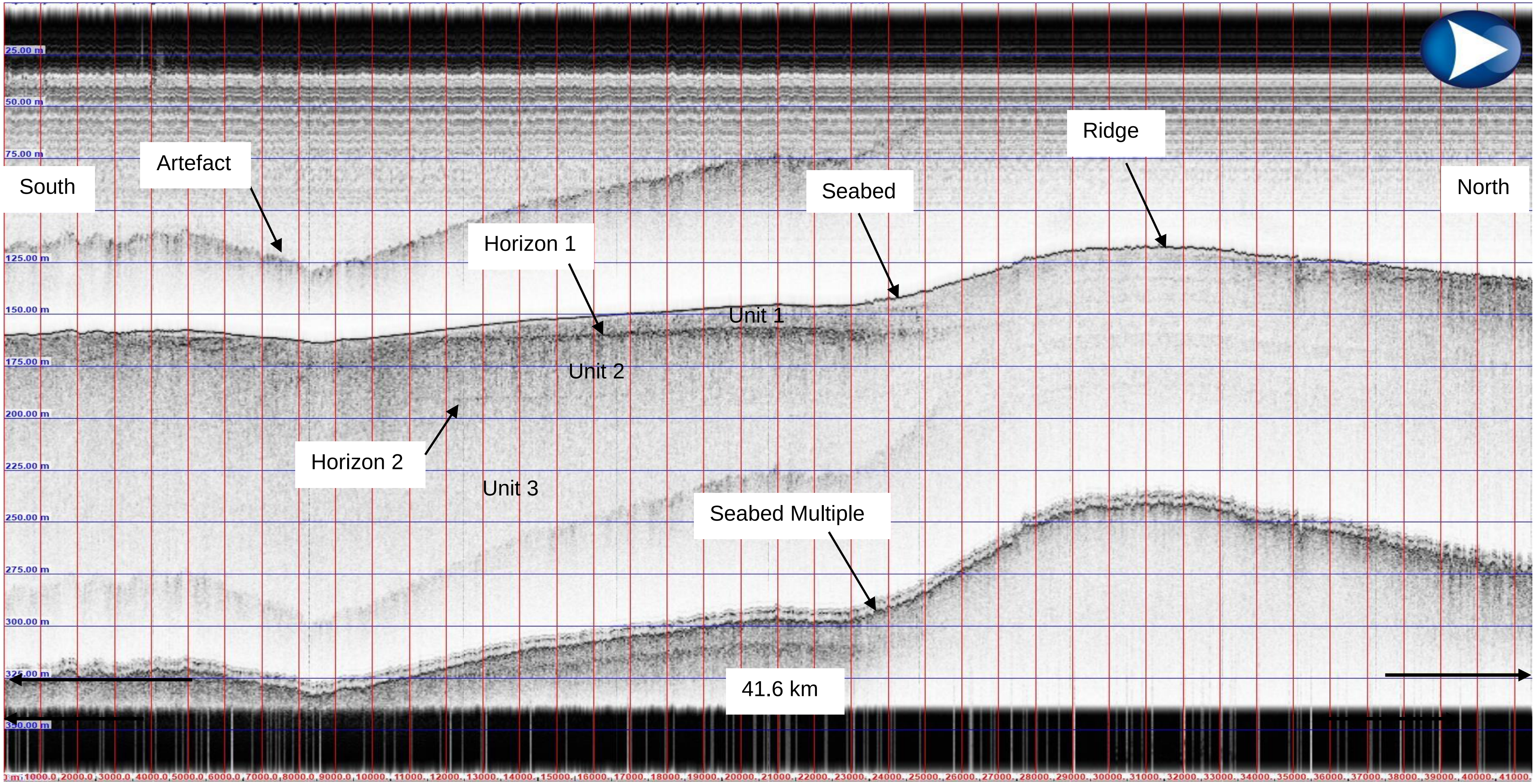


Figure 16: Sub bottom profiler data, cross line 200.

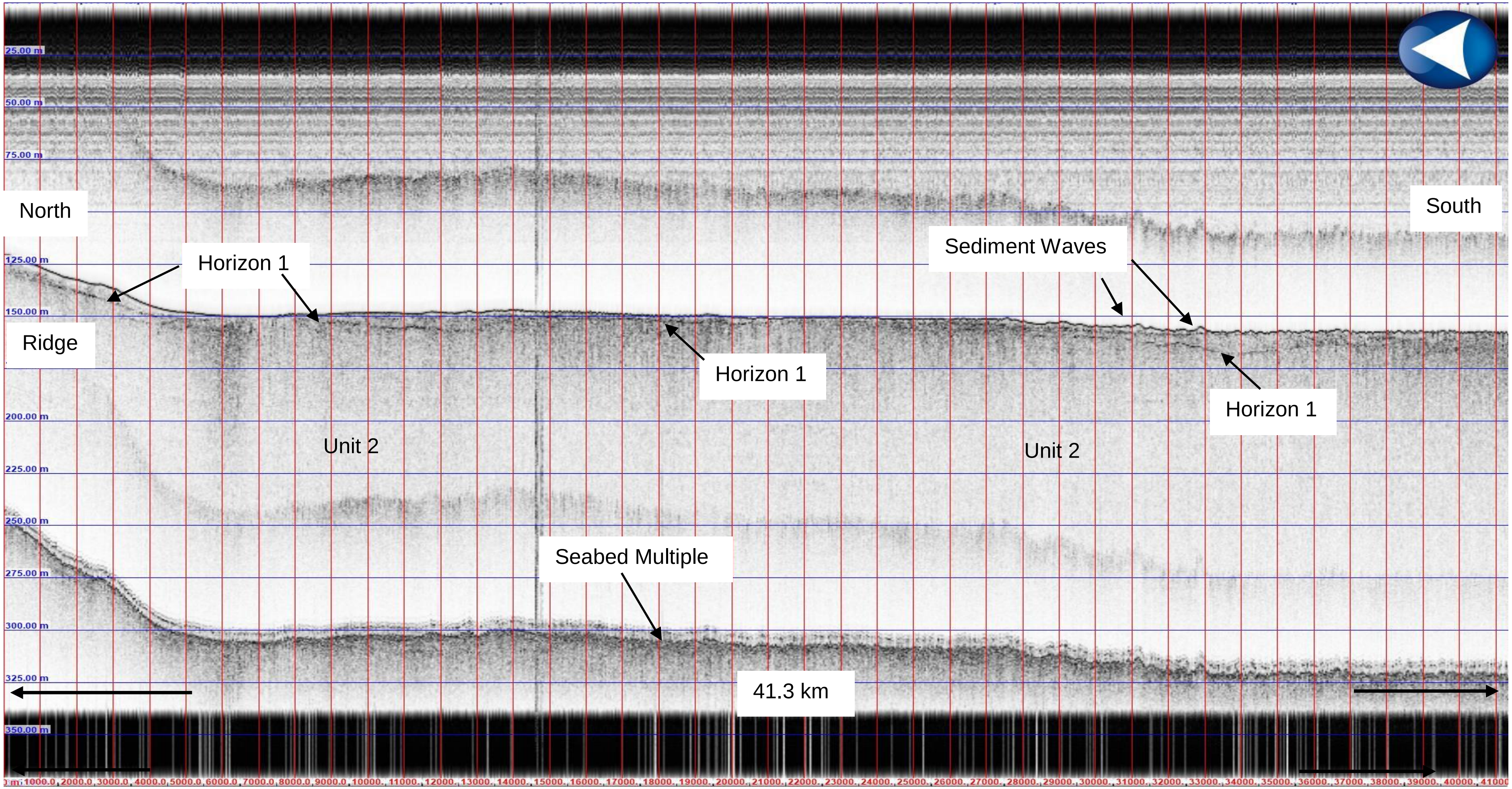


Figure 17: Sub bottom profiler data, cross line 203.

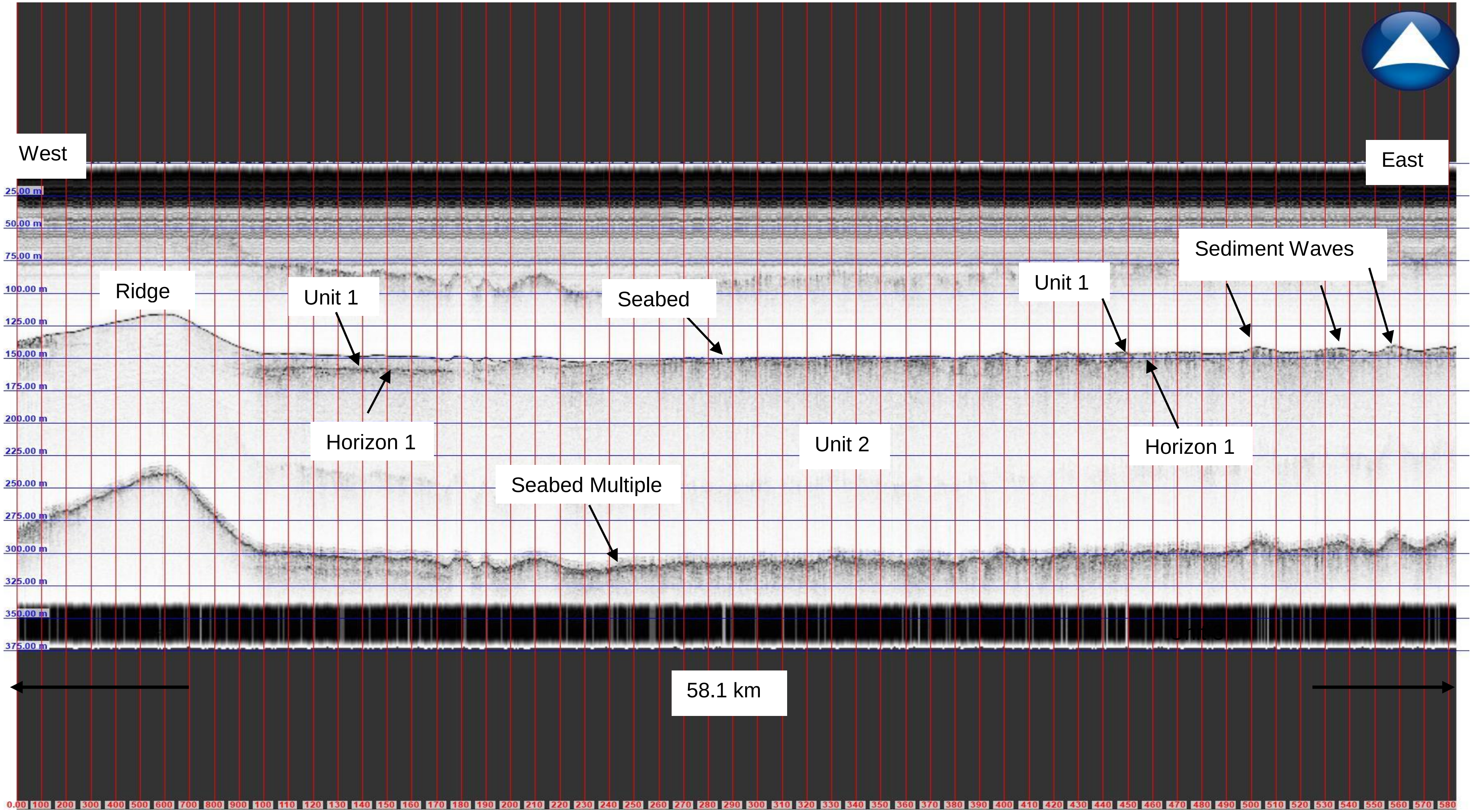


Figure 18: Sub bottom profiler data, main line 99.

4.3.3 Bathymetry

An overview bathymetry image, gridded at 5 m is presented in Figure 19. Water depth varies from 118 to 170 metres. Shallowest depths are located along a prominent ridge crest at the western side of the mapped area. This ridge runs NE/SW and extends beyond the mapped area. The ridge is up to 8 km in width and 30 km in length. Additional bathymetry features of note include two smaller NE-SW oriented ridges, one located in the extreme east of the mapped area.

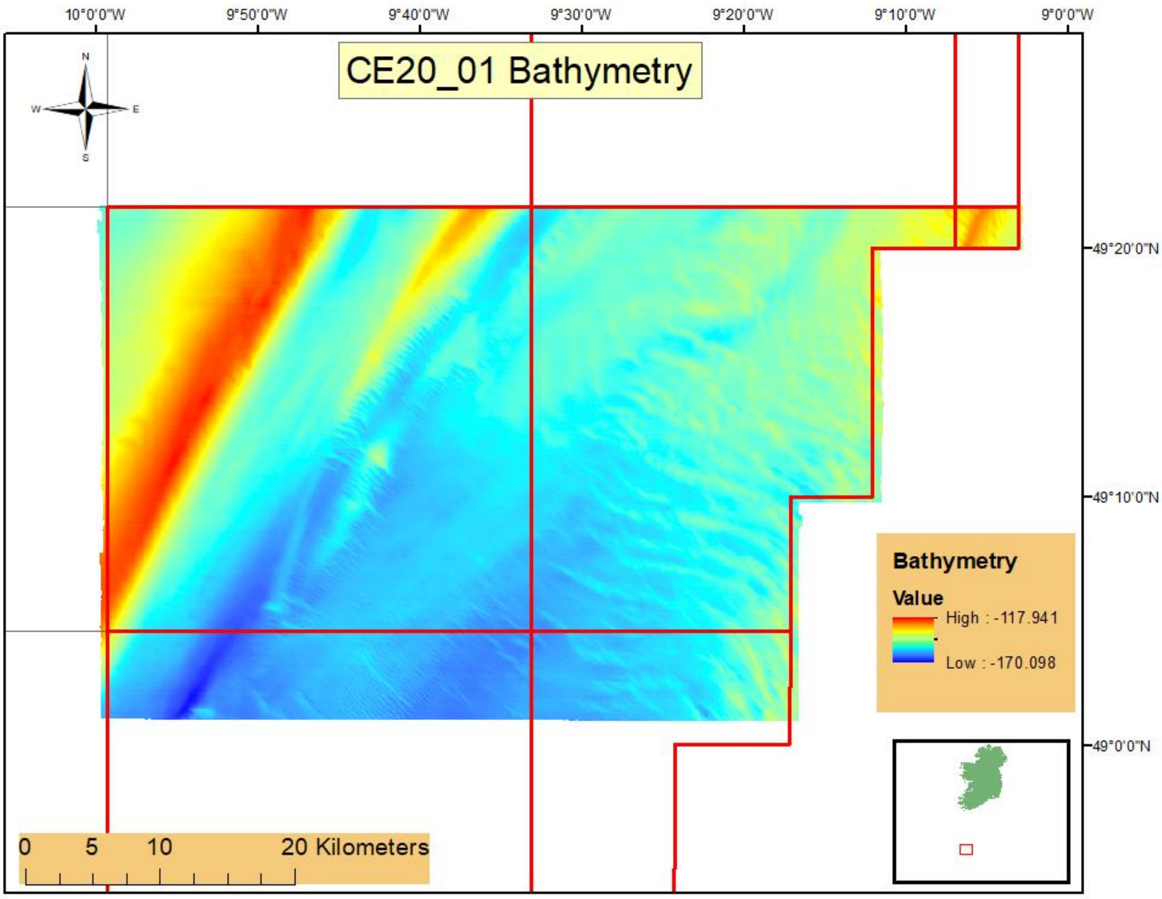


Figure 19: Multibeam bathymetry overview.

Figure 20 illustrates sediment waves in the central part of the area. These waves are generally orientated NW/SE and have a range of appearances from straight to sinusoidal and are often truncated by adjacent waves. Wavelengths are in the order of 200 to 400 metres and lengths of over 10 km are observed.

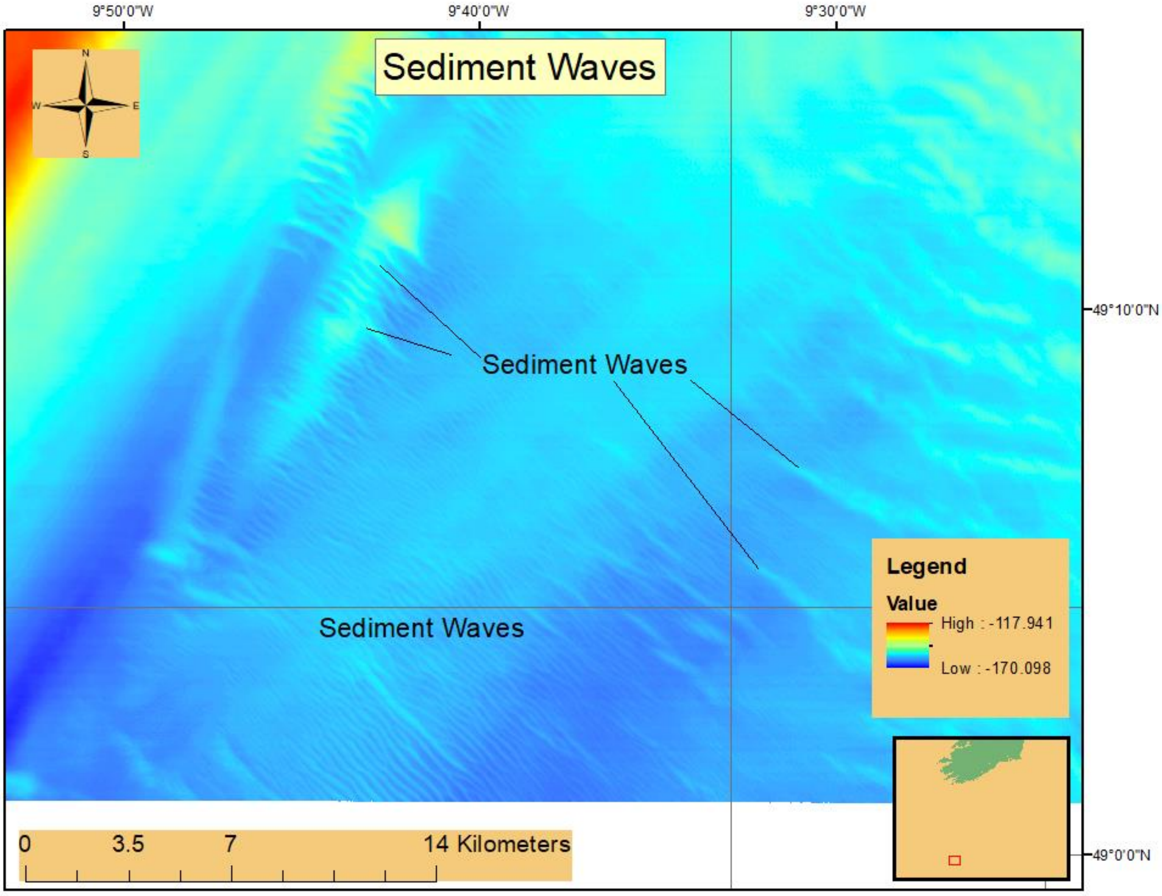


Figure 20: Multibeam bathymetry illustrating sediment waves.

4.3.4 Seabed Texture

Multibeam backscatter is the amount of acoustic energy being received by the sonar after a complex interaction with the seafloor. Analysing the amplitude of the returning sound waves enables us to extract information about substrate structure and hardness, allowing for identification of substrate types. Seabed reflectivity properties depend on the hardness and roughness of the seafloor surface. In simple terms a strong return signal indicates a hard and/or rough surface and a weak return signal indicates a soft, smooth surface.

EM2040 multibeam data was used to produce backscatter images in this report. EM302 backscatter data was also acquired. Figure 21 is the backscatter mosaic for the NW of the area. It illustrates the diverse nature of the substrate. The convention used is that dark coloured areas represent relatively higher intensity (stronger) returns than light coloured areas. Homogeneous low backscatter intensity is the dominant type of substrate in the SE of the image. This area correlates with the lower portion of the ridge slope, discussed in Section 4.3.3.

High intensity backscatter substrate is dominant to the NW of homogeneous low intensity area. The high intensity substrate is broken by lenses of low intensity backscatter. These lenses, orientated NE-SW are up to 1.5 km in length and are typically 100 to 150 metres in width. They form both straight and sinusoidal geometries.

Low intensity backscatter lenses are the dominant substrate type in the NW corner. These lenses are separated by narrow, meandering areas of high intensity backscatter. The low intensity lenses are orientated ESE-WNW. They are wider than the lenses located to the SE.

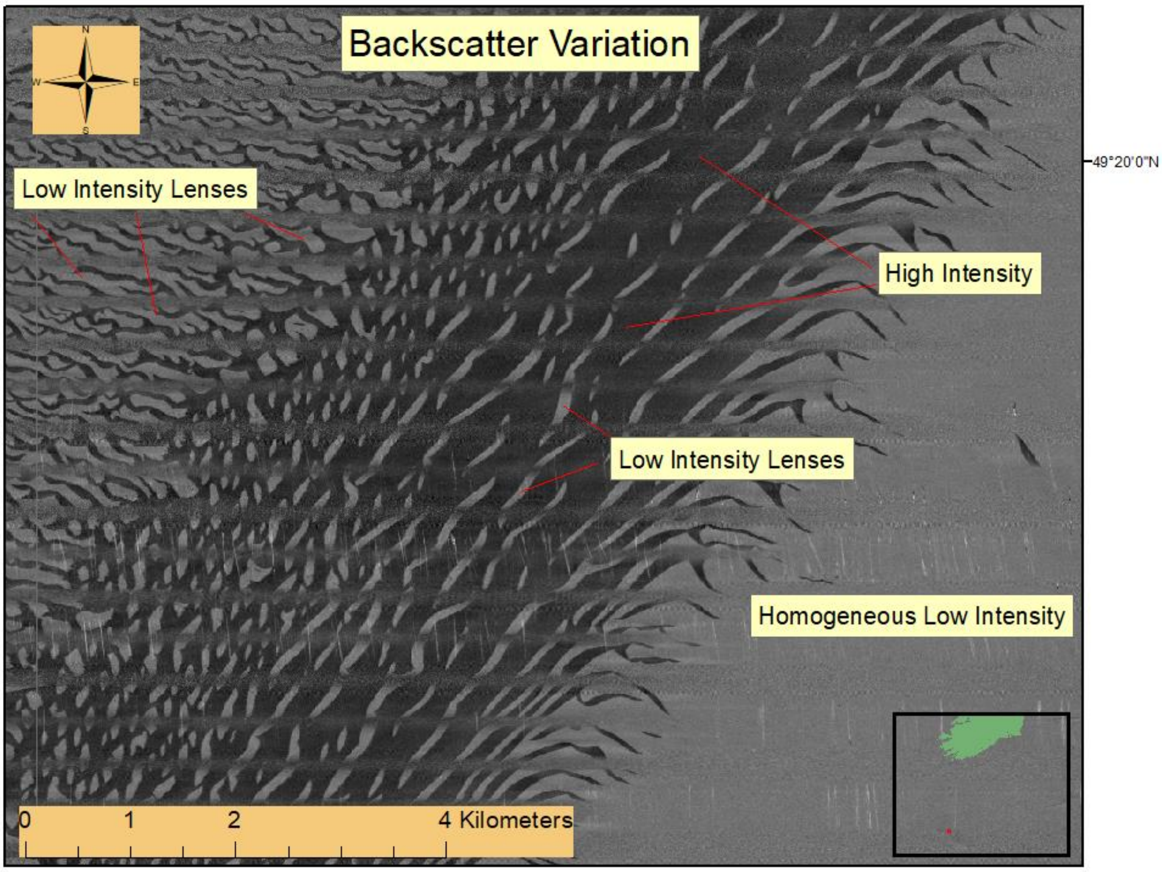


Figure 21: Backscatter mosaic NW portion of area.

Figure 22 shows the backscatter mosaic for the entire area. Relatively low backscatter intensity types are dominant. High backscatter intensity is found mainly in two areas, the NW, where it forms a NE-SW orientated zone that is approximately 4 km in width and in the East where it manifests as linear waveforms and mottled areas interspersed with low intensity lenses.

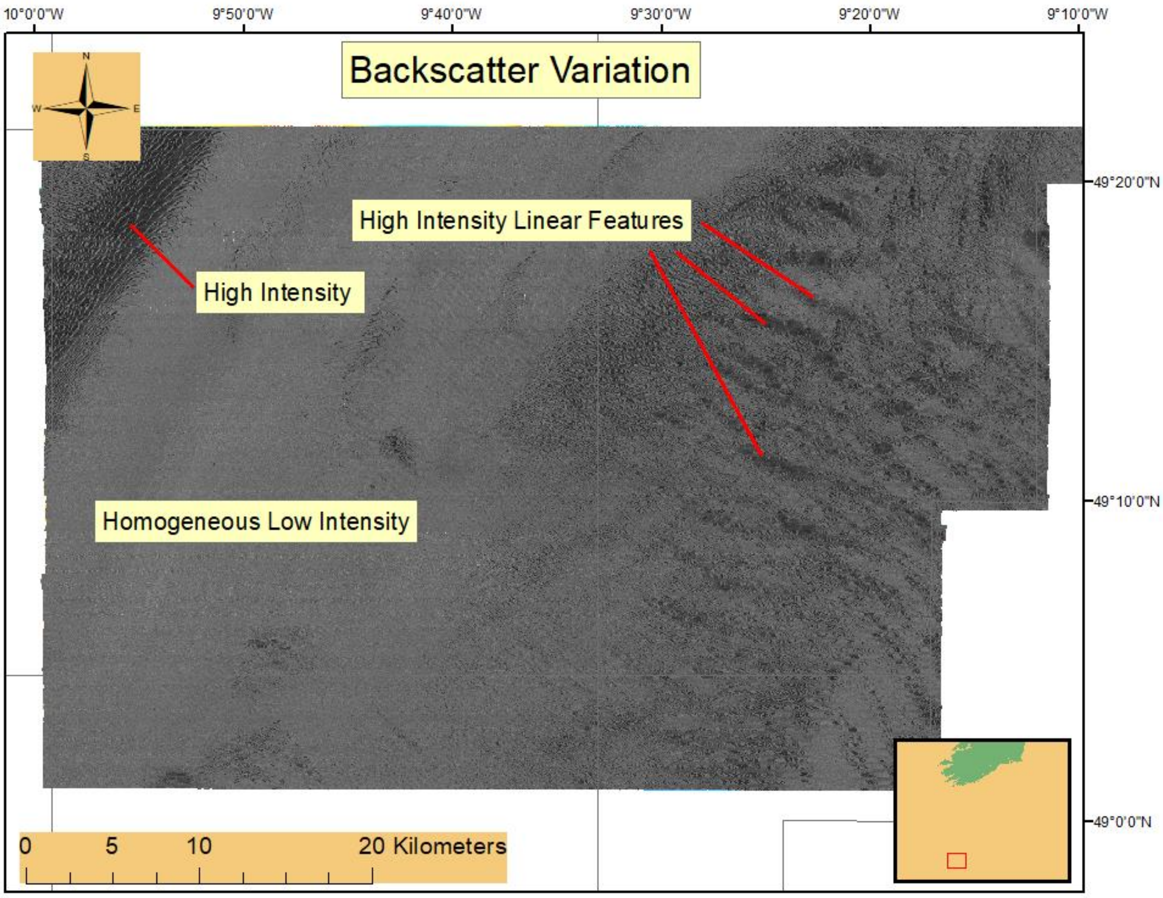


Figure 22: Backscatter mosaic showing variation over entire area.

4.3.5 Seabed Features

Description of seabed features is based on analysis of bathymetric, shaded relief and backscatter data. It is possible to make valid inferences on seabed character and composition by correlating these datasets. Shaded relief data is used to illustrate the features discussed in this section. Shaded relief imagery is produced in Caris by shining an imaginary sun at 35º angle over the depth colour coded multibeam bathymetry dataset.

Figure 23 is an interpreted shaded relief image gridded at 5 metres with sun illumination from the NW. The area shown in the images corresponds with the large ridge crest, evident in the bathymetry. The channels exhibit relatively higher backscatter than the surrounding substrate and they also represent areas of greater depth. Strong currents flowing over the ridge crest have scoured the sediments, leaving a lag deposit on the channel substrates. They range from 20 metres to over 150 m in width.

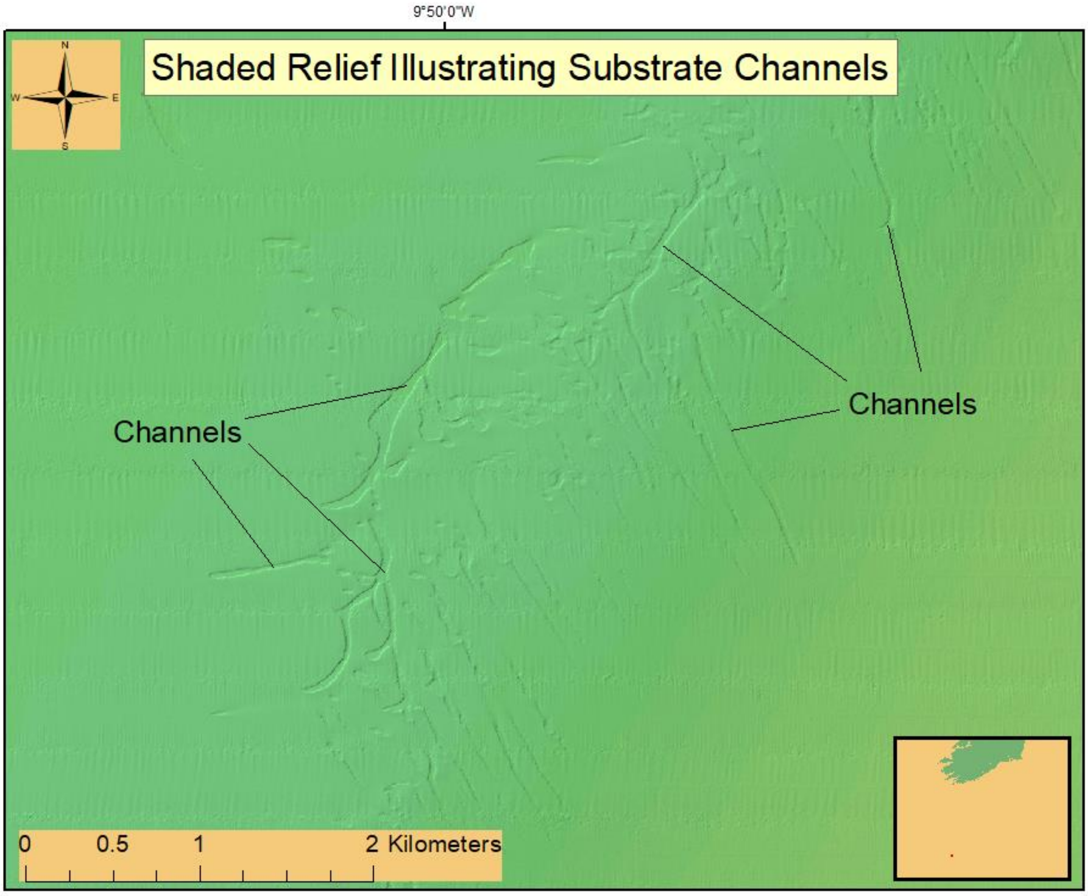


Figure 23: Multibeam shaded relief illustrating substrate channels.

Sediment waves, located in the central part of the survey area are illustrated in Figure 24. Their WNW-ESE axes orientation indicate dominant current from the NE and SW respectively. Wavelengths are in the order of 100's of metres.

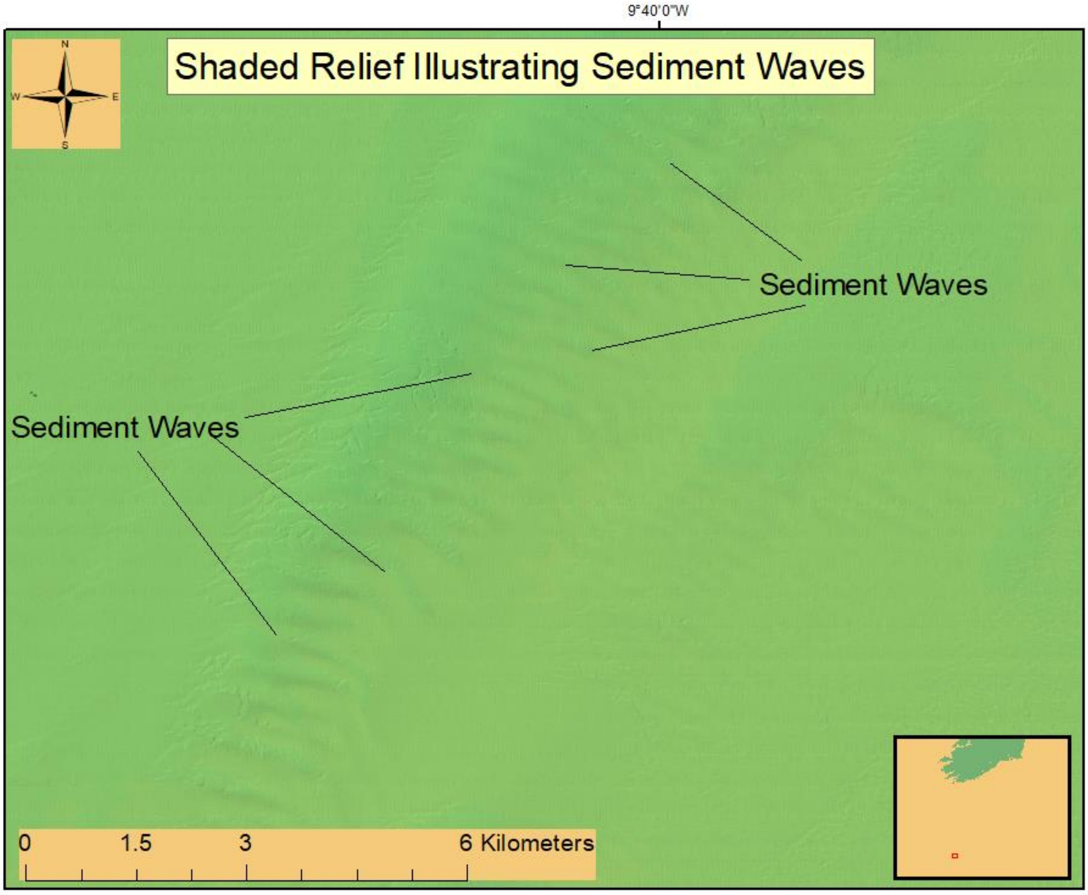


Figure 24: Multibeam shaded relief illustrating sediment waves.

4.4 Groundtruthing

Groundtruthing was not undertaken during this survey. Future surveys will groundtruth this area.

4.5 Wrecks

Six wreck sites were identified from multibeam data. Table 15 lists the wreck metadata.

Number	Length / m	Name	Latitude	Longitude
1	51	Unknown	49°16.376 N	-9º 30.281 W
2	70	Unknown	49°16.086 N	-9º 48.917 W
3	113	Unknown	49°15.185 N	-9º 46.939 W
4	45	Unknown	49°14.777 N	-9º 28.863 W
5	105	Unknown	49°14.849 N	-9º 26.434 W
6	71	Unknown	49°06.284 N	-9º 33.736 W

Table 15: Wreck metadata.

Figure 25 shows the location of the mapped wrecks overlain on the multibeam backscatter data. Mapped wrecks have a red symbol and are numbered corresponding to the table above. UKHO wreck database wrecks are plotted in blue. No actual wrecks were found at those locations. Mapped wrecks are unidentified at the time of writing.

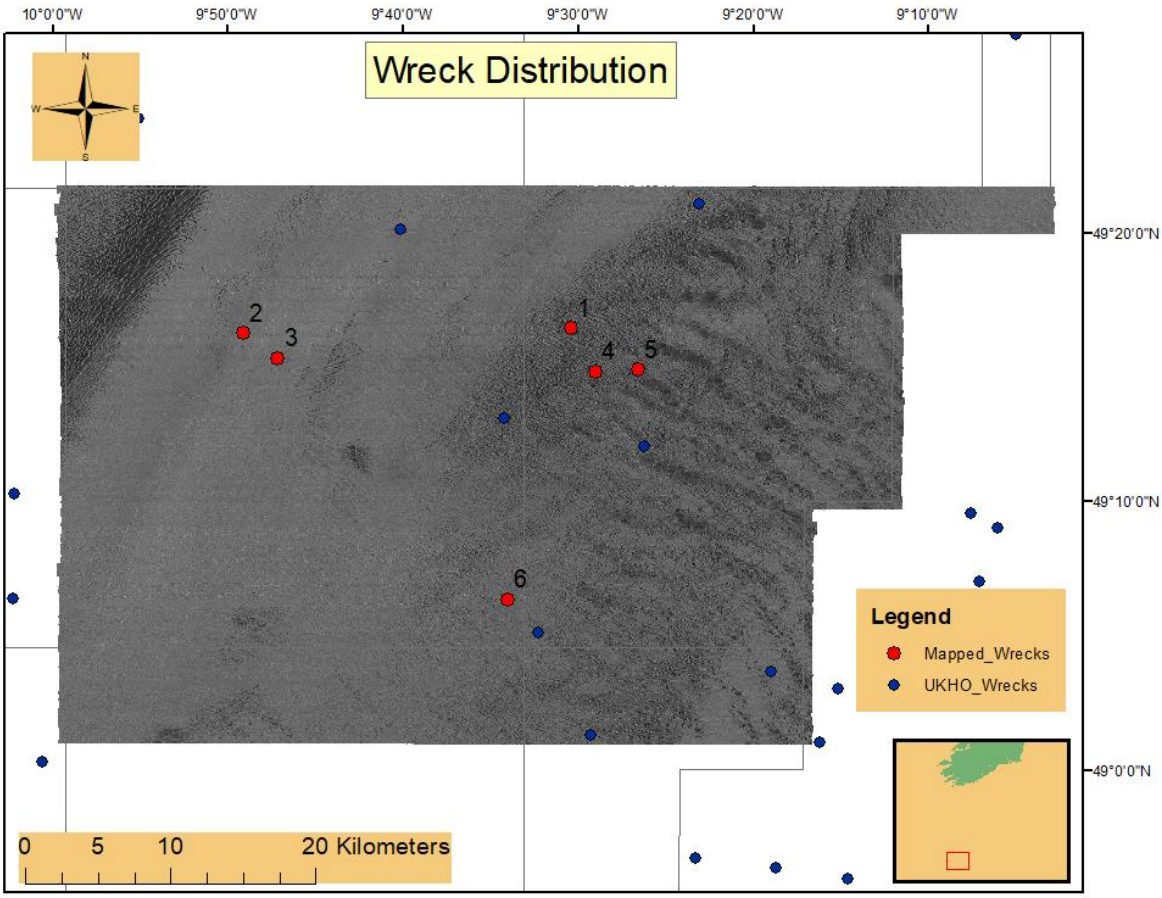


Figure 25: Mapped wrecks overlain on bathymetry.

Figure 26 shows the 3D image of wreck 5. It is located on a flat substrate at a depth of 150 metres and is 105 metres in length.

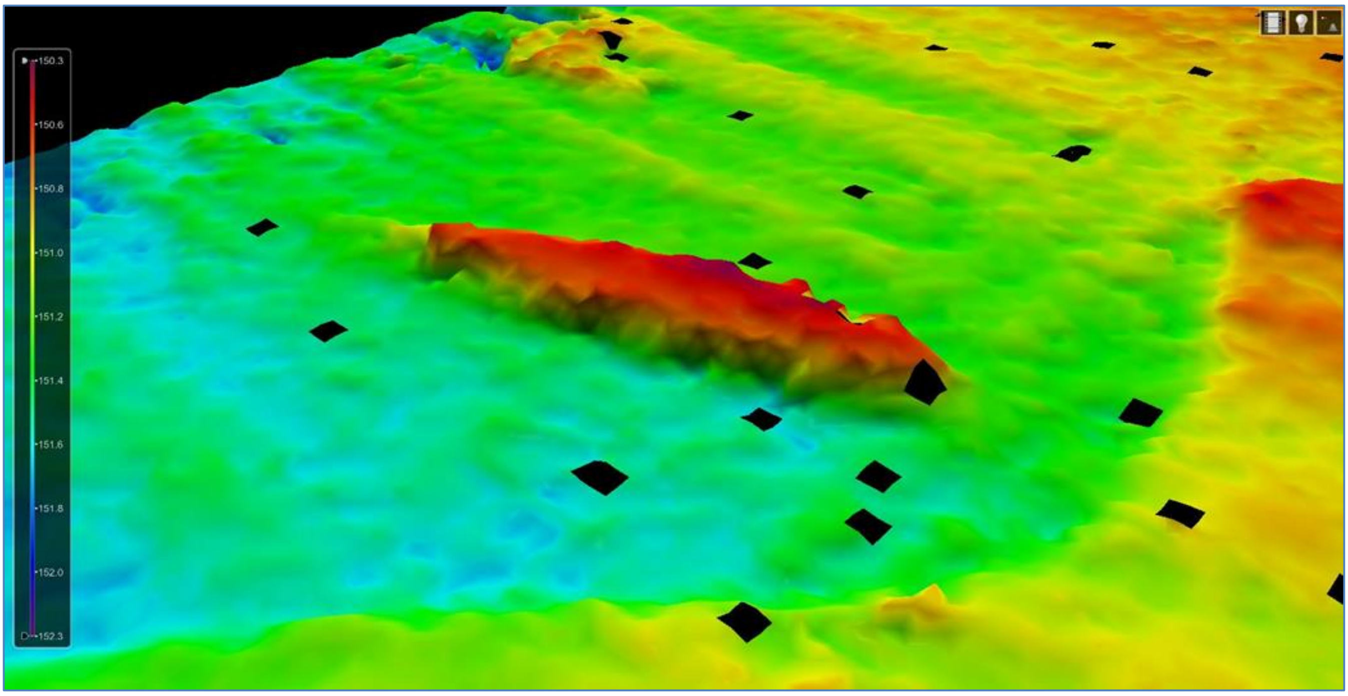


Figure 26: Unidentified wreck 5.